EXPERIMENTAL STUDY ON HYDRODYNAMICS STABILITY OF A SEMI-SUBMERSIBLE OFFSHORE PLATFORM

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CIVIL ENGINEERING
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Experimental Studies on
Hydrodynamics Stability of a Semi-submersible Offshore Platform

by

Ainor Syafarizan Binti Mohamad Yusof

Dissertation submitted in partial fulfilment of
the requirements for the
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CERTIFICATION OF APPROVAL

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Approved by,

(Assoc Prof Dr Saied Saiedi)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

January 2009

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

AINOR SYAFARIZAN BINTI MOHAMAD YUSOF

ABSTRACT

'Hydrodynamics Stability of a Semi-submersible Offshore Platform'. This project is basically will prove on the reliability of design in theory by performing experiment on the scaled model. The experimental are run to provide reliable experimental data for responses of semi-submersible offshore platform and to verify and compare the results with the literature (hypothetical data) on the hydrodynamics stability. The idea of the project was based on the comprehensive design from University of Texas on the "Conceptual Design of a Semi-submersible Floating Oil and Gas Production System for Offshore Malaysia". A semi-submersible platform connected to the sea bottom by anchoring the mooring lines that is functioned to ensure that the platform will maintain on site during operation. Starting with few researches on relevant information of semi-submersible and related floating structures overview; the mathematical calculations is done to analyze the stability of wave impact and the balancing of the substructure weight that will enable the superstructure to float on the water surface. Modelling comes after the entire theoretical part is covered. The fabrication of a scaled model (1:100) of the semi-submersible platform was built in order to compare the experimental hydrodynamics data with the actual performance data to ensure better understanding and clarity of this study. Total number of eight experiments are carried out consist of variation in value of wave height; 0.10 m and 0.20 m; wave period; 2.0 sec and 5.0 sec; and current velocity; 0 m/s and 0.20 m/s. During data gathering and analysis, correction factor is applied to generate the accurate values.

…In the name of Allah, the most merciful and gracious…

Special thanks to;

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'The beauty secret of our excellent achievement lies on commitment,
patient, determination, good cooperation and the very well combination
from all of us…'

- Thank you -

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INTRODUCTION

1.0 INTRODUCTION

1.1 Background of Study

Recent development of oil and gas offshore Exploration and Production (E&P) operations has gone up to thousand depth of deep waters. It requires new technologies and invention to support the very high demand on the high consumptions of petroleum. The earlier types of fixed platform which the substructure is extended and fixed on seabed will significantly very expensive since it requires deeper depth/ length of jacket plus costly maintenance services, etc. Hence, the floating platforms such as Semi-Submersible Platforms are used. As the name implies, floating structure is the structure that is float on water surface that was designed to minimize the effects of wave's motion while maintaining a constant buoyant force and ensure its stability. The semi-submersible is hanged on mooring line that is anchored on the seabed to ensure that it will locate at desired locations.

The study is to carry out experimental studies of the scaled model of a semi-submersible that was designed based on specific scale selection and being constructed for experimental purposes. The final design of scaled model was based on the comprehensive studies from the University of Texas on the "Conceptual Design of a Semi-submersible Floating Oil and Gas Production System for Offshore Malaysia". In the conceptual design was given the weights and dimensions of the platform topsides required for production and drilling, and a location in the South China Sea at water depth of 5,500 ft (1,676 m).

The final hull design was a square ring pontoon with outer length of 270 ft, a height of 40 ft and a width of 55 ft. the ring pontoon is topped with four square columns with a length of 50 ft to a side and height of 80 ft. a square topside deck is supported by the four columns with the corners of the topside deck placed at the geographical centres of column tops.

The physical centres used for small angle stability and input into StabCad for large angle stability were: KG = 70 ft, KB = 29.9 ft, with a draft of 85 ft and freeboard of 35 ft. Six tanks in each pontoon are floodable to reach operational and survival drafts as well as to offset a permanent topsides centre of gravity that is as far form the geographical centre of gravity as (47, 47) ft.

Location	:	South China Sea
Water Depth	:	5,500 ft
General Arrangement		
Pontoon	:	
Outer length	:	270 ft x 270 ft
Height	:	45 ft
Column		
Length	:	50 ft x 50 ft
Height	:	80 ft
Local and global loading		
Software	:	ETABS
Aim	:	moments, deflection, stress acting
Analysis	:	1. structure is floating on constant draft 2. with dynamics wave with the crest of the wave acting on two of the columns opposite from each other
Spring	:	represent mooring lines
Weight estimation	:	fill hull, topsides, ballast tank with water
Wind/wave forces	:	zero in x and y direction
Stability	:	W = B weight equal to bouyancy in opposite direction
Draft	:	85 ft
Freeboard	:	35 ft

Hydrodynamics of motions and loading

Heave	:	21.8 sec
Pitch/roll	:	25.5 sec
Degree analysis	:	0, 22.5, 45, 67.5, 90
Heave mavimum	:	22.5 degree
OP (10 yrs)	:	. +/ - 8.9 ft
ST (100 yrs)	:	. +/- 12.6 ft
Pitch/roll maximum		
OP (10 yrs)	:	.+/ - 2.5 degrees
ST (100 yrs)	:	.+/- 4.3 degrees
Mooring		
Software	:	GMOOR
Analysis	:	1. twelve legs (12) 2. sixteen legs (16)
Division	:	1. 200 ft of 2.75 in 2. 7,350 ft of 3.94 in 3. 300 ft of 3.0 in

1.2 Problem Statement

In real life of practices, the structure is operating on a very deep water level; it is absolutely will be dealing with huge number of forces. It leads to the major challenge for the petroleum exploration field. To support the service life required and to sustain the impact applied to the structure; the most efficient and economical designs are a challenge to the offshore community. The impact on hydrodynamics stability will results in the excellent and smooth operating of the platform inline with the safety requisition by the standard. Semi-submersible platforms have widely been operating for the exploration and production of ocean resources, and many such platforms are now in operation. They are required to be properly designed in order to keep it in position at certain water depth when they are subjected to external forces induced by ocean current, wind and waves.

However, in modelling the floating platform, few considerations and modifications are required since in engineering laws, it has stated that engineer are persistently dealing with models [Chakrabarti, 1994]. In designing the engineering model, it is very crucial that the model is properly scaled in such a way that it is able to show all the main mechanism and allow neglecting some of the particulars for minimalism. The model is used to collect data covers the heave and surge responses that are useful in the design of the semi-submersible for direct use in the design and operation of the structure. Hence, it is considered as the measurement models since these properties and their analysis environment follows certain parallel laws.

The designing of the scaled model will also led to practically higher level of the understanding in the modelling criteria specifications stated by theory to enhance the predominantly comparable results generations with regards to the rule of quantifying, scaling model responses, conventional modelling techniques, and last but not least the capabilities of the wave maker in the laboratory facilities to produce desired scaled wave height and period for the premeditated testing method.

1.3 Scope of Study

This project objective is to verify and compare the guides and formulas in the literature on the hydrodynamic stability of a semi-submersible offshore platform with the scaled model fabricated with explicit obligation stated in the modelling criteria. The tasks were started by carrying out few researches on the real life semi-submersible offshore platform to collect relevant hydrodynamics stability data; heave and surge responses with respect to water fluctuation level. It was the followed by the designing stage of the scaled model test.

During designing of the scaled model test, it is very crucial to ensure that the fabricated model will follow the scaling requirement and the model parameters. The scaling parameters for the results sought in a model test must be established first before a scale is chosen. Once the scaled factor is established, the input parameters may be computed. This may help in deciding on the best testing facility from those available. An appropriate concern must be given to the part and effect of instrumentation on the model. The model instrumentation and the wave tank must be properly calibrated before the model is sited in the tank.

The calibration of the model is very significant. Much helpful information can be obtained from the pre- and post-test calibration. A check of the calibration during the test runs insures accuracy of collected data. It is done by comparing the result of the analysis with the formula and guides available. More over, the testing ought to be properly documented for future references.

CHAPTER 2

LITERATURE REVIEW

2.0 LITERATURE REVIEW

A semi-submersible is a compliant structure used in drilling for oil and natural gas in offshore environments. This superstructure is supported by columns sitting on hulls and pontoons which are ballasted below the water surface that provides excellent stability in rough, deep seas.

Semi-submersible platform has number of legs to provide sufficient buoyancy to cause the structure float, and its weight will keep the structure upright. This structure is generally anchored by cable anchors during drilling operations, though they can also be kept in place by dynamic positioning. Semi-submersible rigs are always spread moored with mooring lines emanating from the four corner columns. Vilain (1972) says that such a spread mooring is possible because unlike ships, the environmental force on a semi-submersible is relatively insensitive to direction.

Known as from the family of floating structure, semi-submersible platforms are being use worldwide. The design of semi-submersibles must satisfy the buoyancy requirement and have a relatively low transit that allows them to be floated to a designated location. There are six degrees of motion that will be experience by the structure during impact of wave and current. It is divided into two which are the translational and rotational movement. It is depends on three dimensional axis of x, y and z. **Figure 2.1** shows the motion of the structure.

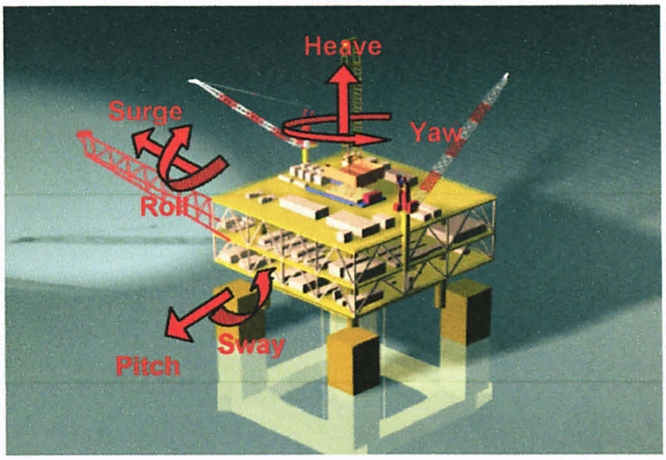


Figure 2.1: Motion of the Floating Structure

According to Chakrabarti, 1994, the scaling will follows Froude's Law and in addition with few simplifications by Reynolds scaling effects. Since the effect of wave and current will be testing in wave tank, modeling a scale-model will be the main focus. It is important to highlight the motion that will be experience by the semi-submersible on the impact of wave forces acting on it.

2.1 Wave Motions

The indications used for describing semi-submersible motion in the translational and rotational directions are shown in **Figure 2.2**. Roll, pitch and heave are greatly reduced by the transparency and by spreading the water plane area. With the spreading of the water plane area, the natural period of the unit increases proportionately.

$$THEAVE = \sqrt{\frac{2m}{\rho g A wp}} \tag{1}$$

Where;

m = mass, 67 kg
ρ = density, 1035 kg/m3
g = gravity, 9.807 m/s2
A_{wp} = water plane area

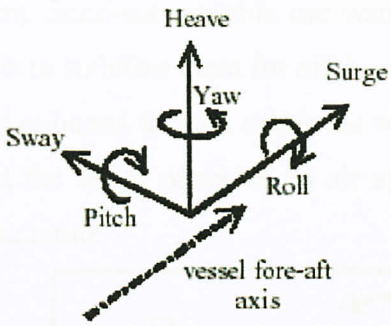


Figure 2.2: Motion Indication

For the hydrodynamics analysis, it only focuses on one degree at a time of freedom which is heave RAO (Response Amplitude Operator calculation). Heave motion is most critical because the basic objective is to drill a hole and to do this one must keep the bit on the bottom of the hole with the proper weight and rotation. Other motions, such as roll and pitch decrease the efficiency of the people working on the vessel and can become critical when severe. **Figure 2.3** shows that a dummy model of semi-submersible obtains its buoyancy from ballasted, watertight, pontoons located below the ocean surface and wave action. The topside is placed on top of the four structural columns that connect the pontoons and topside.

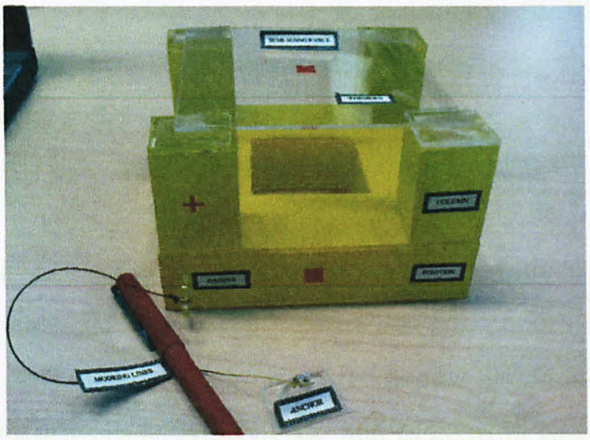


Figure 2.3: Dummy Model of Semi-submersible

Semi-submersible utilizes water ballast to minimize the up and down motion of waves. The fundamental concept of this buoyancy is similar to the concept of filling water in the bottle to be float in water tank shows in **Figure 2.4**. The bottle that fills of ¾ full of water are partially will serve as a model of a semi-submersible platform. Semi-submersible use water in the same fashion as the partially full bottle is to stabilize them for offshore drilling. The water is stored in the pontoons and columns located under the water. The open area between the upper deck and the water provides an air space so that waves can pass freely through the structure.

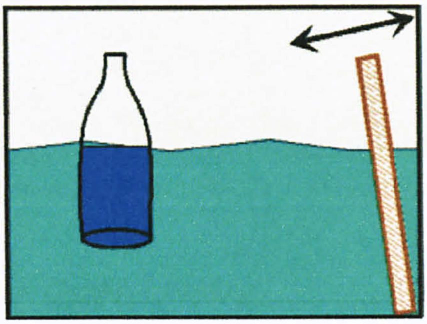


Figure 2.4: Conceptual Stature of Semi-submersible

Moorings and anchors are used to tie platform in place. The material which commonly used for the mooring lines are the steel chain, synthetic fiber rope and steel wire rope. The characteristics of the mooring lines are the catenary shape due to heavy weight and the length of rope is more and the best part of the synthetic fiber is the corrosion free. Most semi-submersibles are anchored to the sea bottom with the mooring chains that shows in **Figure 2.5**, but some use dynamics positioning to keep it stationary in the desired location. Therefore, the platform must have means of producing forces and momentum to counterbalance the environmental forces like wind, currents and wave induces in order to keep it at a standstill.

The design of the semi-submersibles platform should incorporate the water depth, the design wave, the wind loading and soil conditions while performing the required operations. Increasing water depths, of course involve additional materials, which result in greater cost, and increasing wave size with its larger loading, has a similar effects. The stability of the platform is the most important condition where is the effectiveness mooring system will lead to kept in position.

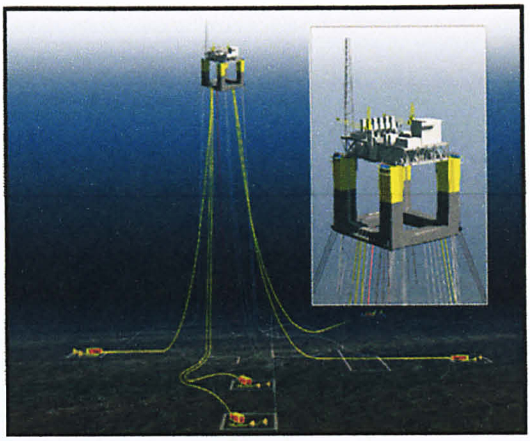


Figure 2.5: Semi-submersible Platform with Mooring Chain.

2.1.1 Local and Global Loading

When design an offshore structure, one of the first and most critical steps is to choose an appropriate method of computing the exciting forces on the structure. The analysis that is performed to the structure will highlight the impact of the hydrodynamics motions on the structure at certain draft. It is important to acknowledge the forces that acting to the hull which is the hydrostatics pressure. This form of pressure is essentially more dominating than wind, wave and current forces. The total pressure is determined by the static and dynamic pressure equations;

$$P_{total} = P_{static} + P_{dynamics} \quad (1)$$

$$P_{static} = \rho g z \quad (1.1)$$

Where: ρ =

$g = 9.81\ m/s^2$

z = water depth

$$P_{dynamics} = \rho g A e^{kz} \quad (1.2)$$

Where: A = amplitude of wave

k = wave number = $2\pi/L$

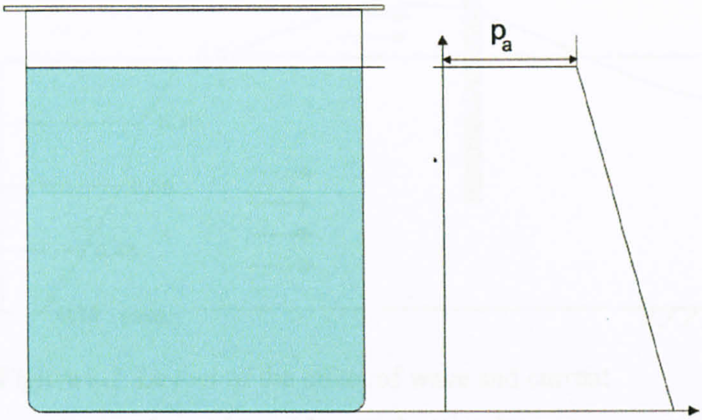


Figure 2.6: Static Pressure Distribution

Figure 2.6 shows that the impact of pressure with respect to depth according to the equation (1.1). As the depth is increasing, the static pressure will increase as well.

Another method of force computation is the wave diffraction theory. The empirical Morison formula is on of the most popular method used to determine forces on offshore structures. The Morison equation is used to calculate the response of the structure. It assumes the force to be composed of inertia and drag forces linearly added together, and is usually applicable when the structure is small compared to the wavelength:

$$f = \rho C_M \frac{\pi D^2}{4} \dot{u} + \frac{1}{2} \rho C_D D \mid u \mid u \qquad (2)$$

in which D is pile diameter; f the horizontal force per unit length; u the wave particle velocity in the horizontal direction and $\dot{u}$ the wave particle acceleration in the horizontal direction. The empirical constants CM; coefficient of inertia, and CD; drag coefficient are hydrodynamics coefficients.

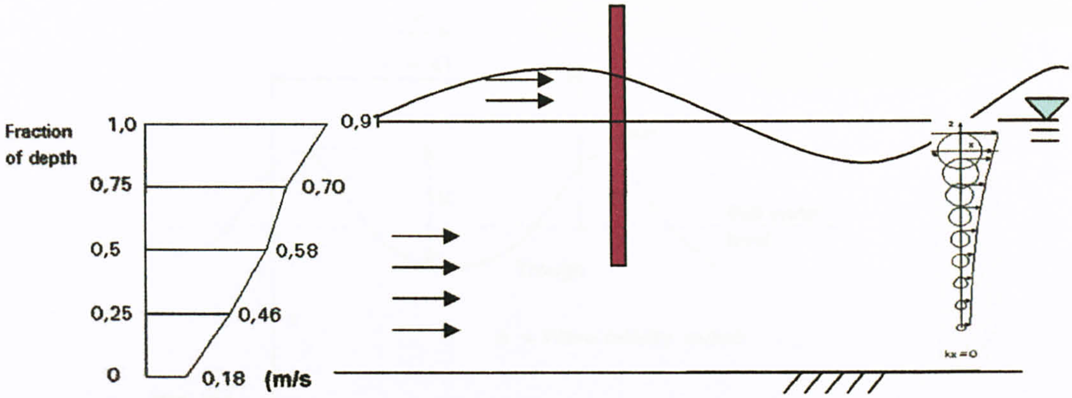


Figure 2.7: Layout of the effect of wave and current on cylindrical member with particle orbit dynamics.

2.1.2 Wave Theory

The most important environmental loading of an offshore structure is the wave loading. The forces on the structure are caused by the motion of the water due to the waves which are generated by the action of the wind on the surface of the sea. Determination of these forces requires the solution of two separate, though interrelated problems. The first is the sea state computed using an idealisation of the wave surface profile and the wave kinematics given by an appropriate wave theory. The second is the computation of the wave forces on individual members and on the total structure, from the fluid motion.

As describe in the kinematics of waves of water, wave theory is the basis of potential theory. In exacting, they provide the calculation on the particle velocities and accelerations and the dynamic pressure as functions of the surface elevation of the waves. The waves are said to be long-crested, i.e. they can be described by a two-dimensional flow field, and are characterized by the parameters: wave height (H), period (T) and water depth (d) as shown in **Figure 2.8.**

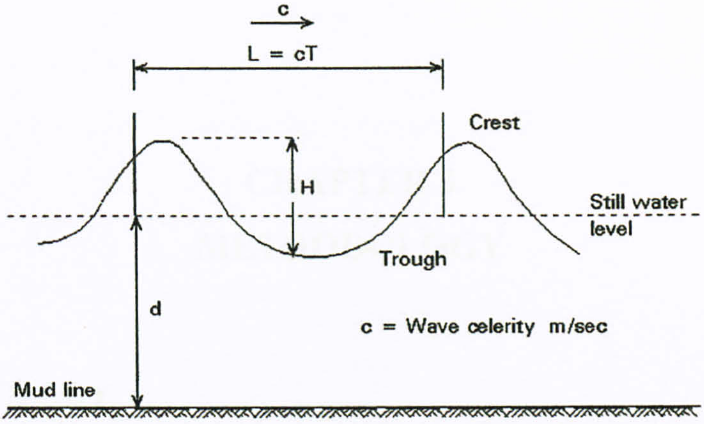


Figure 2.8: Wave Symbols

2.1.3 Pierson-Moskowitz Equations

As refer to book of Chakrabarti (1987), Pierson and Moskowitz in 1964 had proposed a new formula for an energy spectrum distribution of a wind generated sea state based on the similarity theory. This spectrum commonly known as P-M model has since been extensively used by ocean engineers as one of the most representative for waters all over the world. They assumed that if the wind blew steadily for a long time over a large area, the waves would come into equilibrium with the wind. This is the concept of a fully developed sea. Here, a long time is roughly ten-thousand wave periods, and a "large area" is roughly five-thousand wave-lengths on a side. The P-M model has been found to be useful in representing a severe storm wave in offshore structural design.

The P-M spectrum model is written as:

$$S(\omega) = \alpha g^2 \omega^{-5} \exp\left[-0.74\left(\frac{\omega U_w}{g}\right)^{-4}\right] \tag{3}$$

Where;

a = 0.0081
ω = angular frequency, 2π/T
g = gravity acceleration, 9.81 m/s

CHAPTER 3
METHODOLOGY

3.0 METHODOLOGY

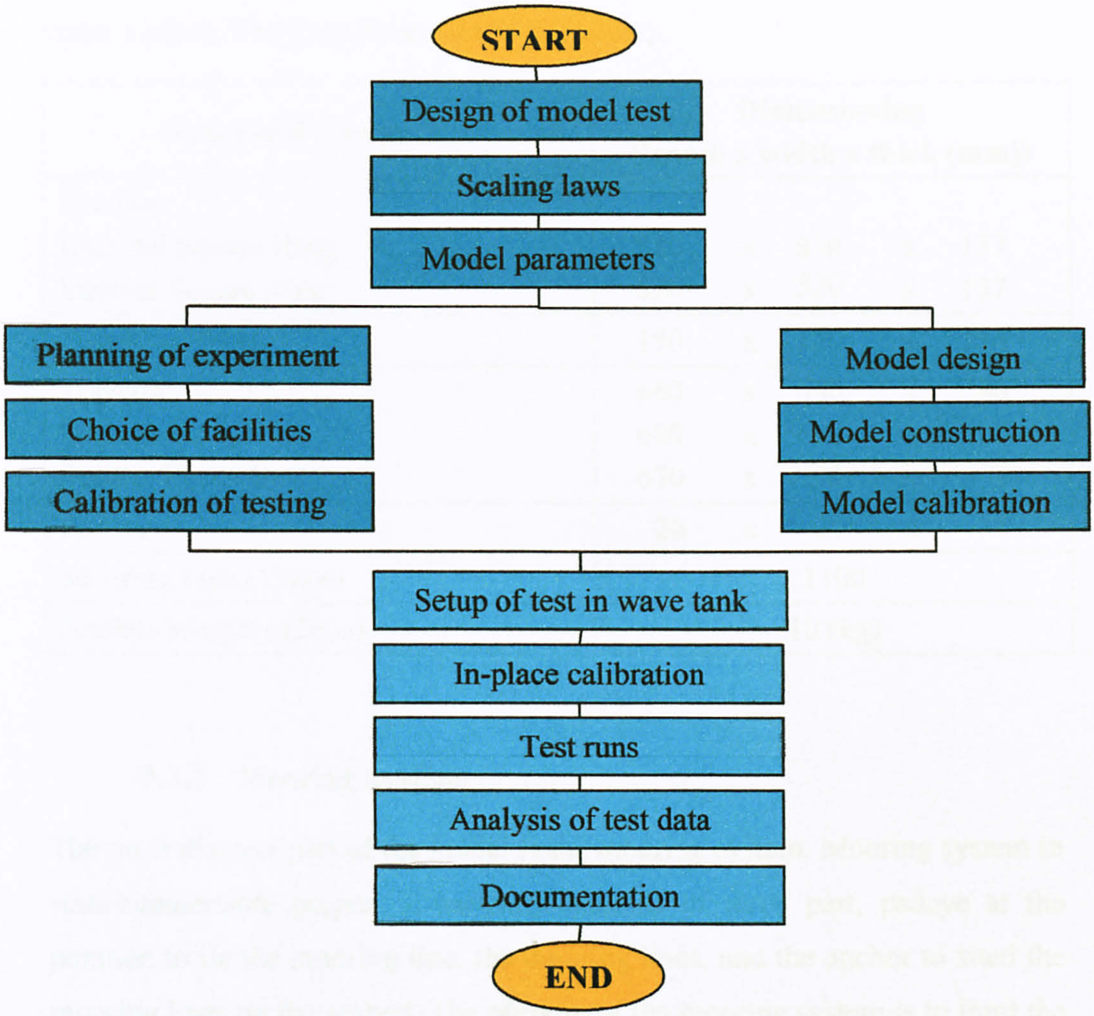
The research and investigations is based on certain laws. The theoretical facts will be gathered first from the available information on related topics of floating structure in addition with the finding and understanding the basic fundamental concepts and carrying out the engineering mathematical calculations to support the literature. The next stage of modelling guide will follow the Chakrabarti, 1994. The accurate and workable scaled model need to specify the entire requirement and specification generated in the conceptual design.

3.1 Design Selection

The data from the conceptual design of the semi-submersible platform is scaled down to the scale of 1:100. The picture of the conceptual design is as shown in the figure below.

Figure 3.1: Layout of the Conceptual Design of Semi-submersible

The design follows the comprehensive report provided in terms of the dimensions and weight in order to achieve the same centre of gravity and the centre of buoyancy as such given in the report. The scaled model development was accomplished as per planned in FYP 1. As the carry-over for the previous FYP I tasks, the second part of the project were executed this semester. The continuation for completing the scaled model is accomplished. A planning of general procedure is outlined below.



3.2 Design Stage

The design stage has undergone few phases before it can be preceded with the fabrication work. It includes; dimensioning, material selection, and weight formulation.

3.2.1 Dimension

The scale factor is 1:100 based on the Chakrabarti due to the facilities constraint and the workability of the experimental setup later on. The final design of the scaled model of the semi-submersible platform consists of a square ring pontoon on the bottom part of the substructure and superstructure is supported by columns to cause the structure float, and its weight will keep the structure upright sitting on hulls or pontoons which are ballasted below the water surface. The final dimension is as follow;

Structural Component	Dimensioning (length x width x thick (mm))
Pontoon External Square Ring Internal Square Ring	 830 x 830 x 137 520 x 520 x 137
Columns (4nos)	150 x 150 x 234
Topside Topside Cover Splitter Plate (4nos)	680 x 680 x 80 680 x 680 x 10 670 x 50 x 6
Padeye	20 x 20 x 4
Mooring Line (12nos)	1100
Anchor Weight (12nos)	10 (kg)

3.2.2 Mooring System

The most discreet part of the model is the mooring system. Mooring system in semi-submersible project is basically consists of three part; padeye at the pontoon to tie the mooring line, the mooring lines, and the anchor to sited the mooring lines on the seabed. The purpose of the mooring system is to limit the semi-submersible movement so that the platform remains in place over the equipment on the sea floor.

The material mooring is nylon wire. The size of the mooring does not required any scaling since there is no restricted concern in the forced impact to the mooring lines. The length of the mooring line is determined by applying the concepts of trigonometric. The lines are positioned to 45° from vertical with 30° from horizontal and 15° between each line. The calculation of determining of the mooring length is as below since the platform is allow to move 450mm off center in any direction for drilling purposes.

$$x' \cos 45 = 500$$

$$x' = 710 \text{ mm}$$

since;

off center $= 450$ mm

Horizontal length $= 340 + 450$

$= 790$ mm

New mooring length $= (790^2 + 500^2)^{1/2}$

$= 900$ mm

Thus, the total length of the mooring line is said to be 900 mm.

The next element of the mooring system is the anchor. The anchor is made by steel tube weighted of 10.0 kg. The preferred weight of the anchor is calculated according to the drag force impact on the structure that will be encounter by the anchor to locate the mooring lines on a rigid location.

$$\text{Drag Force, } F = 0.5\, C\rho A V^2 \tag{4}$$

$$\text{Reynolds Number, } R = \rho\, VD / \upsilon \tag{5}$$

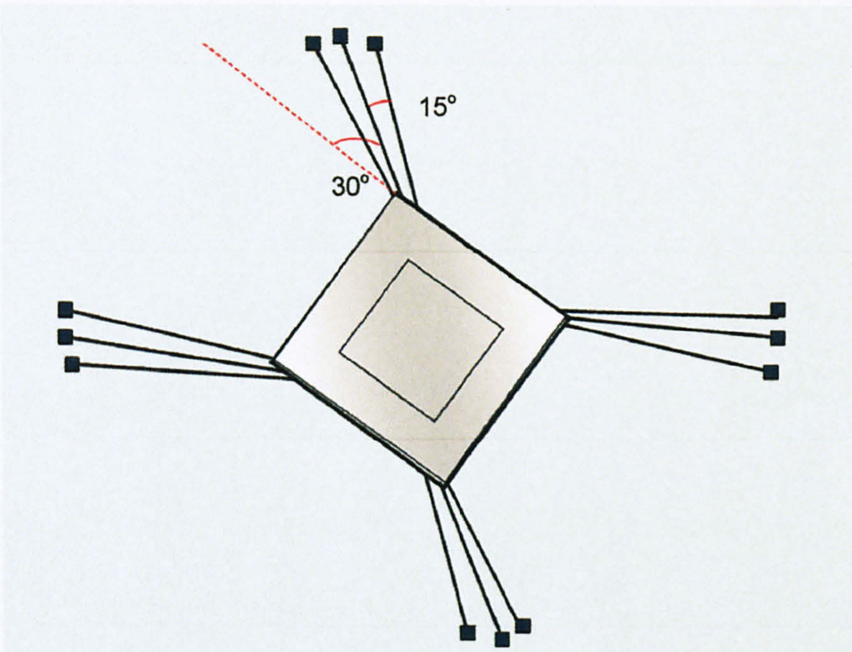


Figure 3.2: Plan View of Mooring System

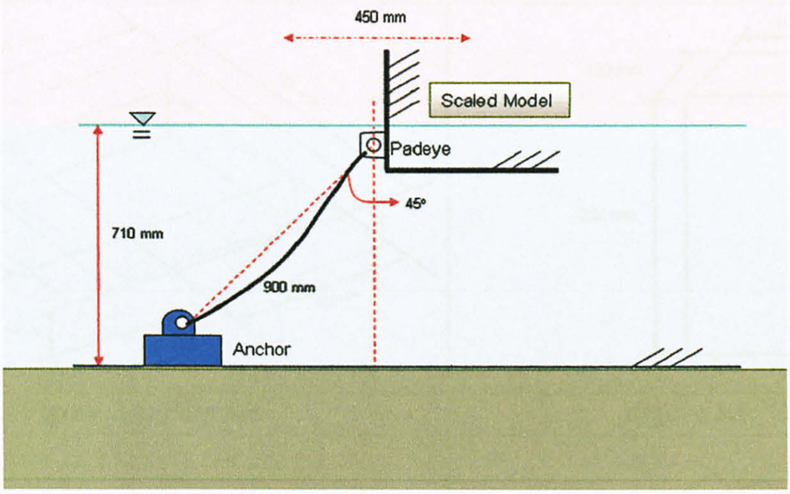


Figure 3.3: Layout of determining the length of mooring lines

Final sketching with dimension of every each component of the scaled model;

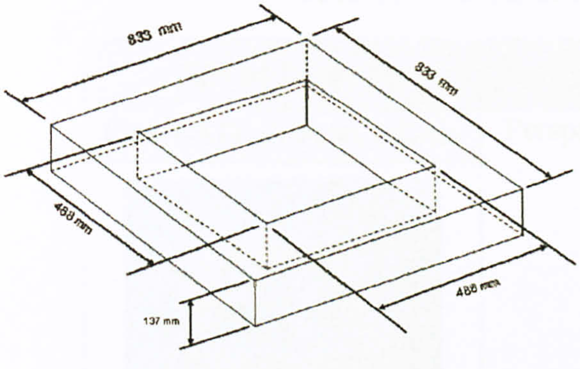


Figure 3.4: Pontoon

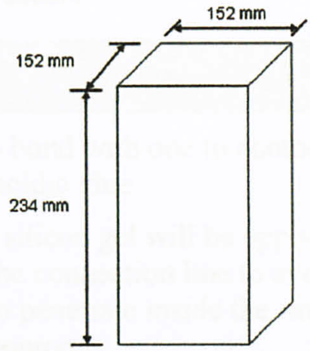


Figure 3.5: Column

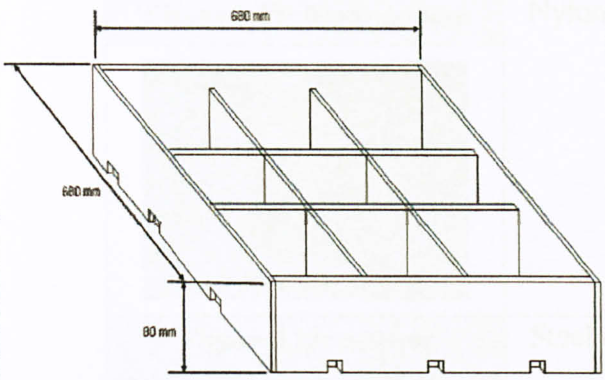


Figure 3.6: Topside

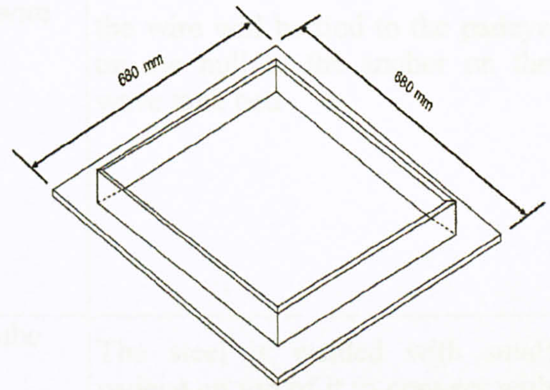


Figure 3.7: Topside Cover

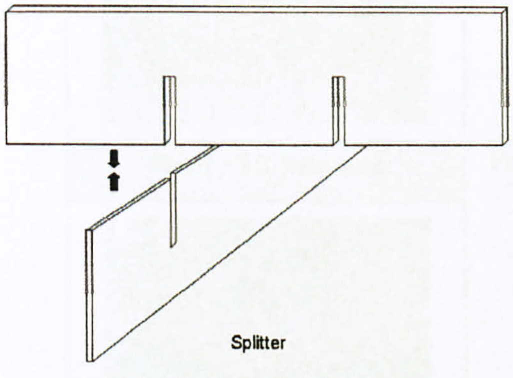


Figure 3.9: Compartment Splitter

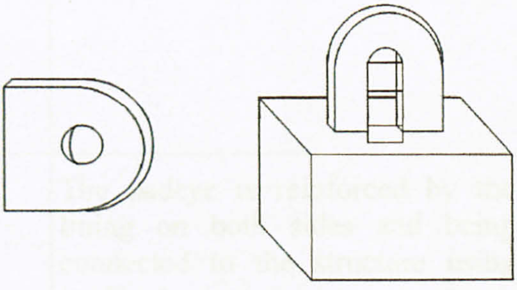


Figure 3.10: Padeye (left) and Anchor (right)

3.2.3 Material Selection

Table 3.1: Material selections and details

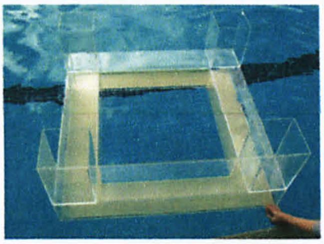
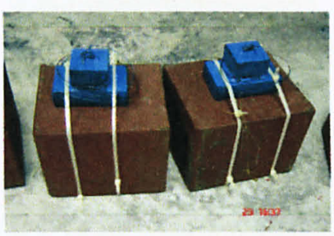
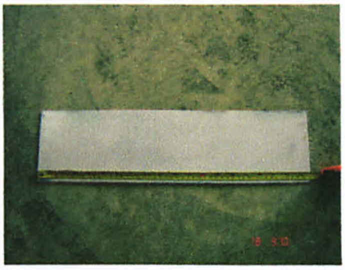
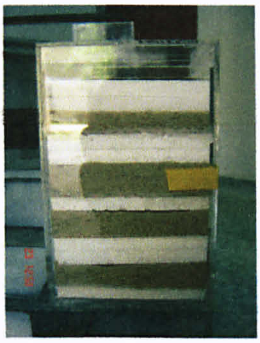
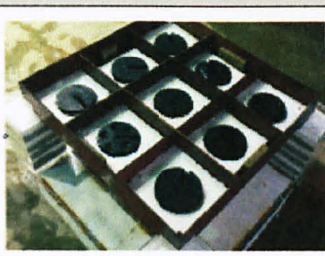
Part of structure	Materials	Description
Figure 3.11: Pontoon, column 	Perspex	- bond with one to another using acidic glue - silicon gel will be apply to cover the connection line to avoid water to penetrate inside the ring and pontoon
Figure 3.12: Mooring line 	Nylon wire	the wire will be tied to the padeye on the hull to the anchor on the wave tank bed
Figure 3.13: Anchor 	Steel cube	The steel is welded with small padeye on top of it to connect with the mooring lines.
Figure 3.14:Padeye 	Perspex	The padeye is reinforced by the lining on both sides and being connected to the structure using acidic glue
Figure 3.15: Topsides 	Plywood	The topsides is placed on top of the four columns on the geographically centre point at each of the column

Figure 3.16: Added Weight 	Steel Plate	The added weight is function achieve the desired draft and also to varies the distribution of loading on the structure
Figure 3.17: Added Weight 	Sands	The added weight is function achieve the desired draft and also to varies the distribution of loading on the structure
Figure 3.18: Added Weight 	Polystyrene	The added weight is function achieve the desired draft and also to varies the distribution of loading on the structure
Figure 3.19: Added Weight 	Steel Rounded Plate	The added weight is function achieve the desired draft and also to varies the distribution of loading on the structure

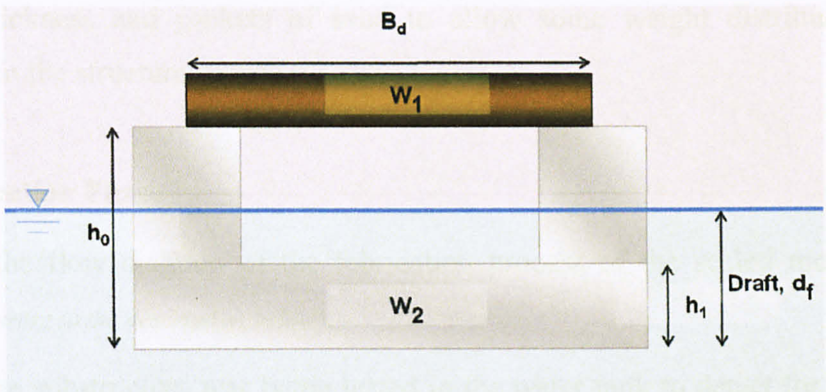
3.2.4 Weight Formulation

The designed scaled model is desired to follow the conceptual design so as to achieve the required buoyancy and weight. This is to ensure that the experimental result later is tally with the literature. The buoyancy is modeled as point force at the geometric center of the submerged portion of the column with magnitude equal to the weight of displaced water.

$$B = W \tag{6}$$

Where;
B = buoyancy
W = volume of water displaced

To calculate the weight specifically for each component of the structure to achieve certain depth of draft, few calculations need to be carried out to determine the amount of added mass required. The formula is as below;



$$W_1 + W_2 = \gamma_w \left[V_p + 4 \times A_c \times (d_f - h_1) \right] \tag{7}$$

Where;
W_1 = weight of substructure
W_1 = weight of superstructure
γ_w = water specific density, 9806 N/m^3
V_p = volume of pontoon
A_c = cross section area of column
d_f = depth of draft
h_1 = height of pontoon

** *(Details calculation of the weight allocation in appendix III)*

After final calculation, the weight variation is tabulated in table below;

Table 3.2: Weight Allocation and Distribution.

Structural component	Weight allocation (kg)	Initial weight (kg) (main structure only)	Added Weight (kg) (to be added)
Superstructure (Topsides)	23.27	5.27	18.00
Substructure (pontoon)	30,31	7.43	22.88
Substructure (column)	15.44	3.46	11.98
TOTAL	69.12		

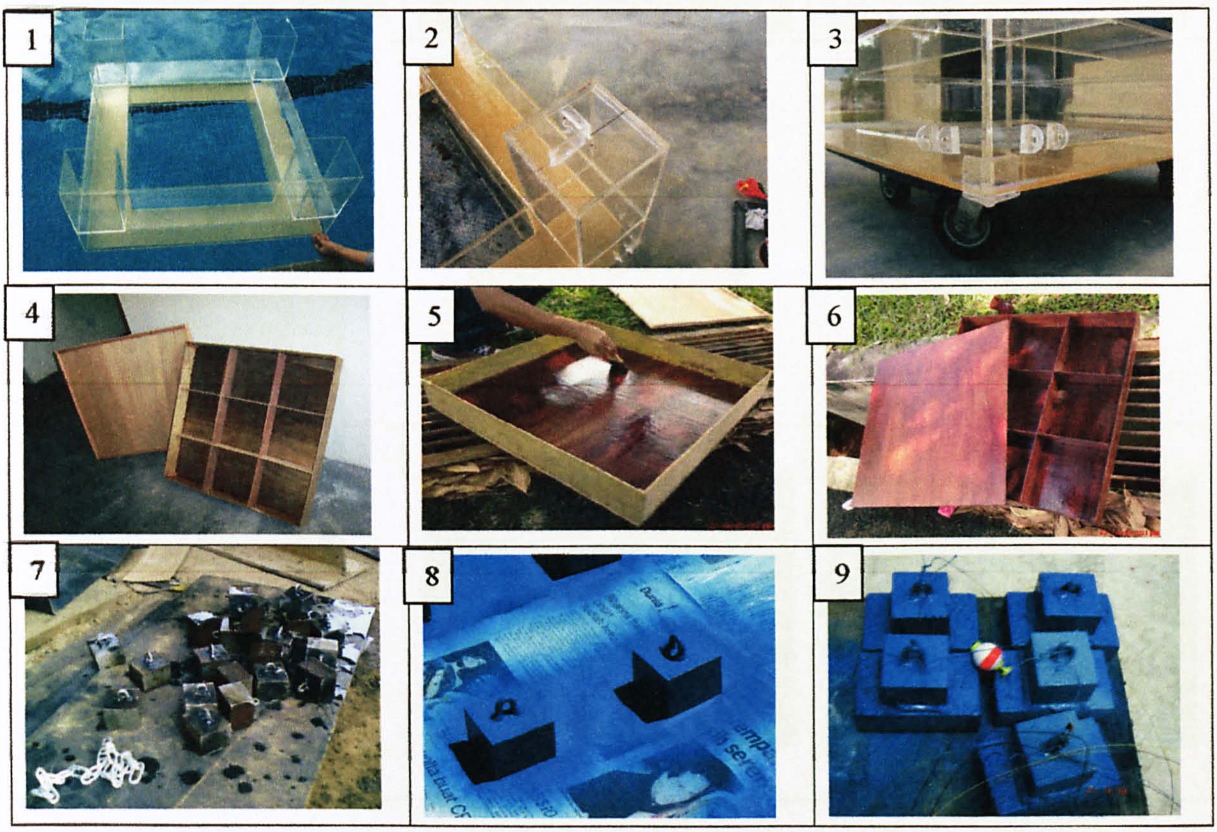
Thus, in order to achieve the desired weight, it was decided to add some weight temporarily and the added weight is ensuring to be removable for future use. The selected materials for added weight consist of the steel plate of specific thickness and packets of sand to allow some weight distribution uniformly to the structural member.

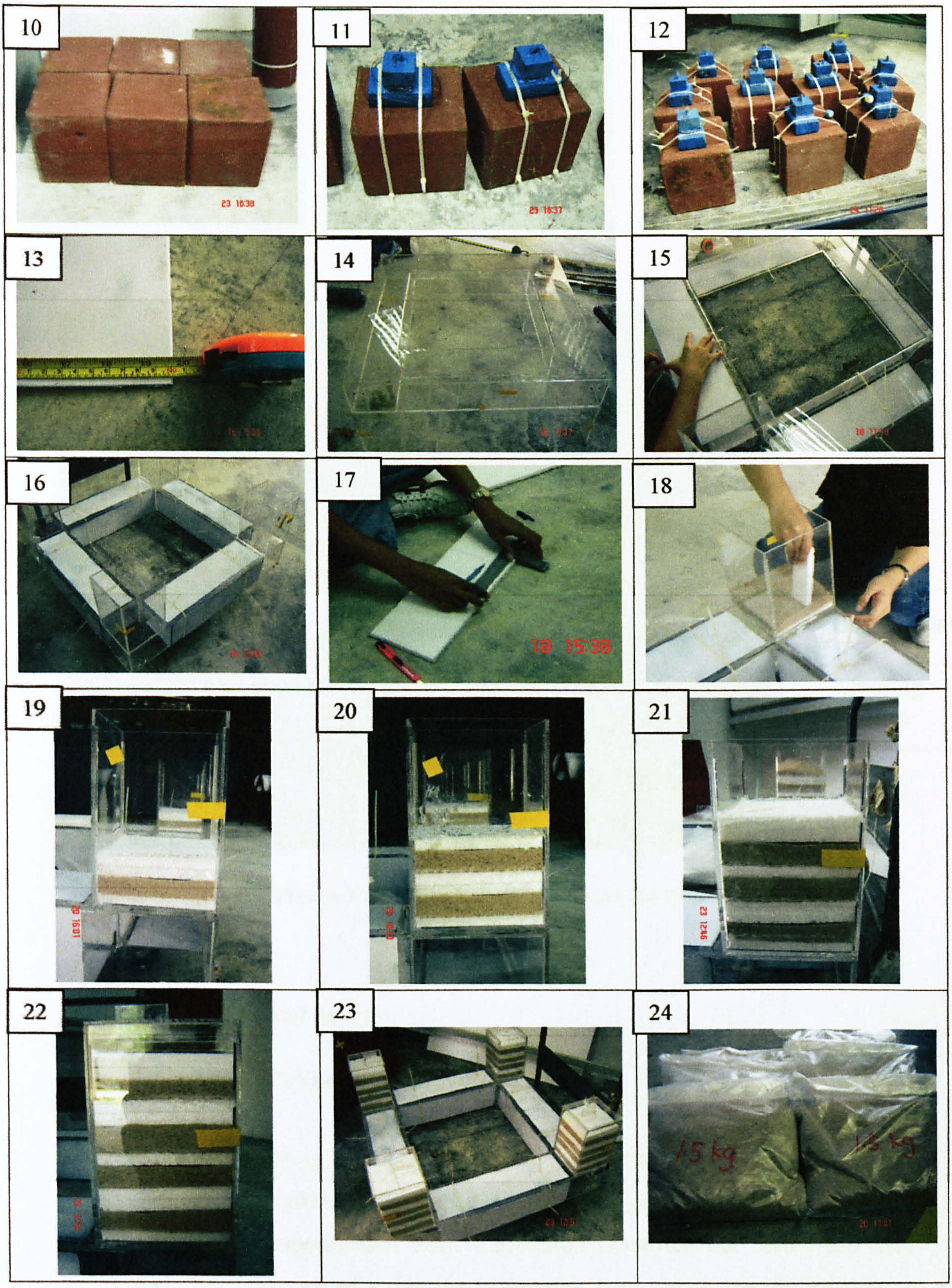
3.3 Fabrication Phase

Below is the flow diagram of the fabrication process of the scaled model. (*Refer numbering to the description below*);

1. The substructure was being tested in the water tank to detect for any leakage.
2. The topsides holder was pasted on top of the cover of the column.
3. The padeye was pasted on the side of the pontoon wall reaching the end of the edge of the pontoon.
4. The topside.
5. Varnish was applied to the wooden topsides to enhance its durability when working with water.
6. The topside was fully covered by the varnish layer.
7. The anchor right after being welded with the hook pin.
8. The anchor was painted in blue to avoid corrosion.
9. The anchor.
10. Extra steel weight to be stick to the anchor.
11. The anchor had been tied to steel mass using cable tie.
12. The anchor.

13. The steel plate.(length = 500mm, width = 130mm, thickness = 3mm)
14. Substructures before modification.
15. The steel plate was tied to the model.
16. The steel plate was tied to the model.
17. Polystyrene was cut to pieces as the layer for the sand in the column.
18. Sand was poured into the column box.
19. First layer of sand.
20. Second layer of sand.
21. Third layer of sand.
22. Fourth layer of sand.
23. Final modification of substructure.
24. Packets sand as added mass.
25. Packets sand was arranged accordingly inside the topside compartment.
26. The experimental set up was done in the wave tank.
27. The result was taken by using video capturing the motion of the structure for a certain given wave height, frequency and time.




10
11
12
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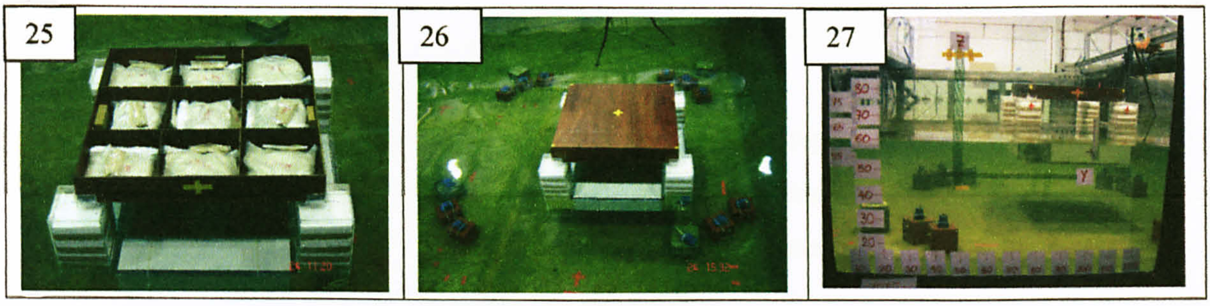
21
22
23
24
15 kg
15 kg



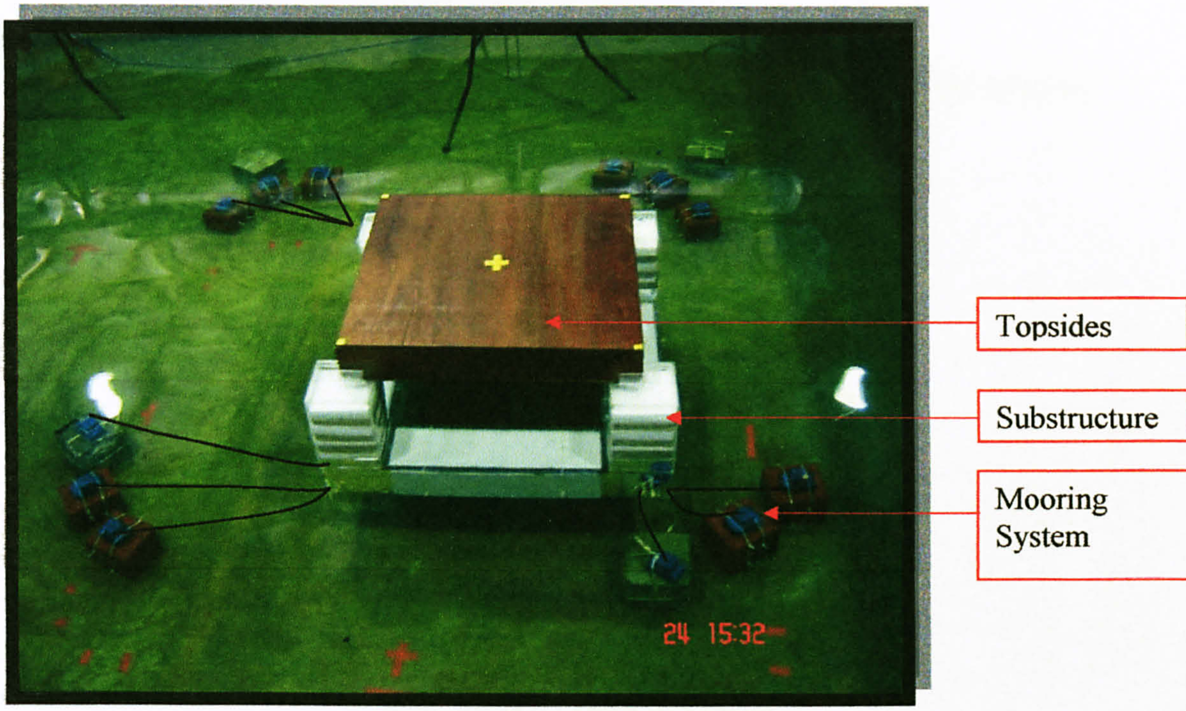


Figure 3.19: Layout of Semi-submersible Platform

3.4 Experimental Setup

3.4.1 Calibration Method

Force on the mooring lines is measured by connecting one of the mooring lines to the hanging digital scale on the bridge. Readings are taken along with the running of the experimental tests. Calibration is carried out before the tests started. The objective of doing the calibration is to obtain the exact value of force generated during experiment that is subjected to friction and stiffness of the nylon rope.

Procedure:

(i) Water is drained out from the tank.

(ii) The nylon rope is connected from the hanging scale on the bridge at one end (A); the other end is connected to the scale inside the wave tank (B).

(iii) Nylon rope B is pulled to certain range of forces; 4, 8, 12, 16, 20 (kg).

(iv) Reading at nylon rope A is recorded.

(v) Based on the reading at A and actual forces at B, a calibration graph is plotted to generate an equation.

(vi) The equation will be used for calculating the actual forces at the mooring line during the experiment later.

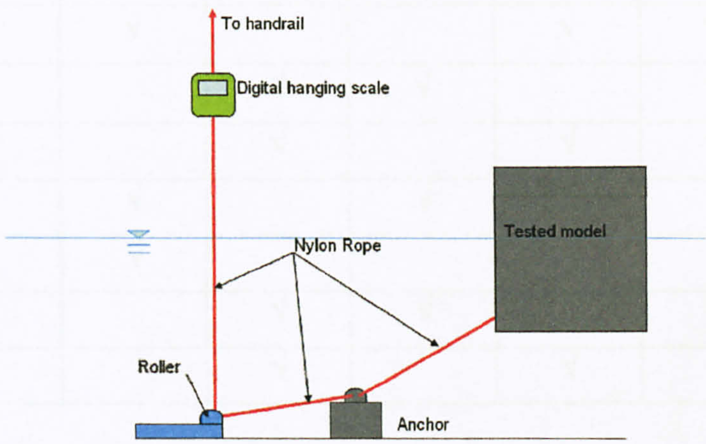


Figure 3.20: Calibration Method

3.4.2 Experimental Method

The testing of the scaled-model was run in the wave tank in the Offshore Laboratory facilities. Objective is to study the response of the scaled model in wave tank under the effect of wave and possible current.

Procedure:

(vii) Water is drained out from the tank.

(viii) The setting for the total area required is marked with the distance of 1.5 m from the wave absorber and 3 m from the side of the wave tank.

(ix) The anchors are placed on the mark provided and the mooring lines are fixed to the anchor.

(x) The scaled model is then being position at the centre and the mooring lines are tied up to the padeye on the scaled model.

(xi) Water is filled up to 700mm height.

(xii) The tests are running for 5 minutes for each test and the responses of the model are captured with the video camera.

Total of eight tests were carried out consist of;

Table 3.3: Experiment Setup

Test no.	**Wave height, cm**		**Wave period, s**		**Current velocity, m/s**	
	10	**20**	**5**	**2**	**0**	**0.2**
1	√		√		√	
2	√			√	√	
3		√	√		√	
4		√		√	√	
5	√		√			√
6	√			√		√
7		√	√			√
8		√		√		√

3.4.3 Data Gathering and Analysis

The numeric value for the experiment was controlled by the computer. However, during the data gathering and analysis, the wave height and the wave period is being recalculated to obtain the accurate value. Whilst for the velocity of current, the value taken is only based on the system.

Procedure for data gathering and analysis:

(i) The video clip contains of five minutes of responses for each test is trimmed to generate the most prevailed period of one minute. (NOTE: The one minute of period is taken towards the end of the five minutes and thus the first couple of minutes are neglected to allow the wave motion to be uniform.)

(ii) Transparent gridline paper is stick to the monitor.

(iii) The wave height and wave period is measured and reading is recorded.

a. **Wave height**; the maximum water level minus the minimum water level.

b. **Wave period**; account for 10 cycles of wave and clock the timing. Then, divide the 10 with the time recorded to obtain the wave period for each cycle.

(iv) The video clip is played and paused for each one second and reading is recorded in tabulated data. Three reading is taken which includes the response of heave, surge and the water fluctuation.

(v) Correction factor is applied applying the concept of trigonometry; the formula for the correction factor is;

$$\frac{C1}{C2} = \frac{Lc}{(L_C + L_M)}$$

(vi) Graph of responses versus time is plotted to observe the results.

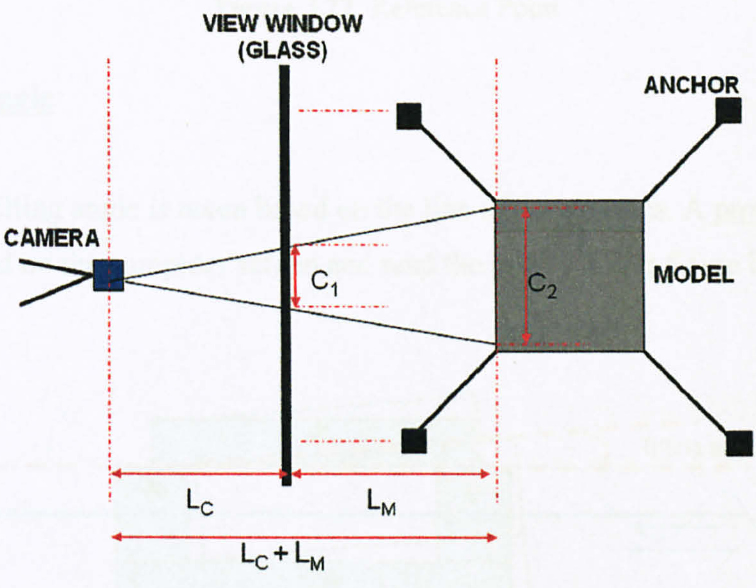


Figure 3.21: Correction Factor Adjustment

Data Collection for responses

1. The zero is taken before the any disturbance in the water.
2. For <u>water fluctuation</u> response, the water line is following the mark 'w', which is similar in vertical line level with the mark 'A'.
3. Mark 'B','C' and 'D' is neglected because in few of the tests the model has moved towards to the right side of the windows.

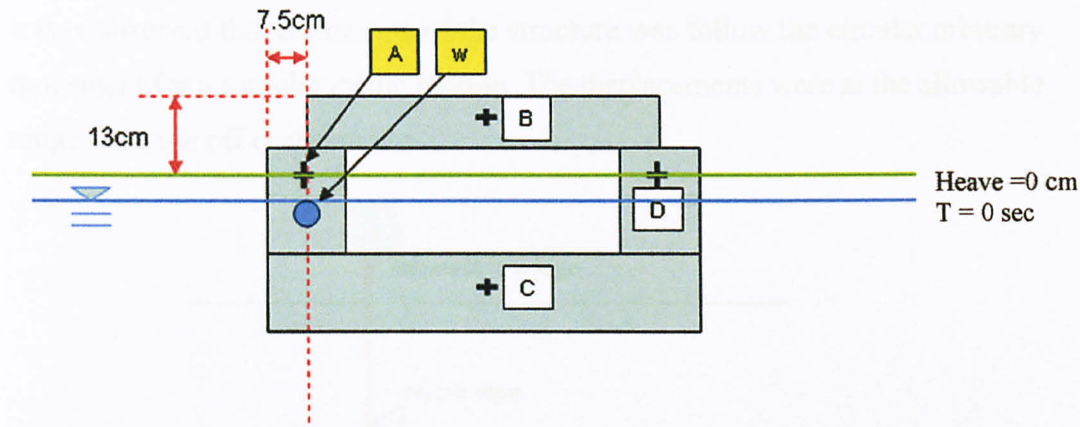


Figure 3.22: Reference Point

Tilting angle

1. The tilting angle is taken based on the line of the topsides. A <u>protector</u> is placed on the computer screen and read the angle. Refer figure below;

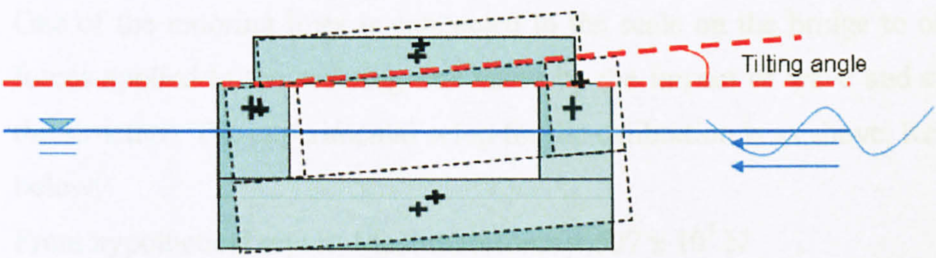


Figure 3.23: Tilting Angle Measurement

CHAPTER 4
RESULT AND DISCUSSION

4.0 RESULT AND DISCUSSION

It was observed that the motion of the structure was follow the circular arbitrary movement for a singular cyclic motion. The displacements were at the allowable range from the off centre radius.

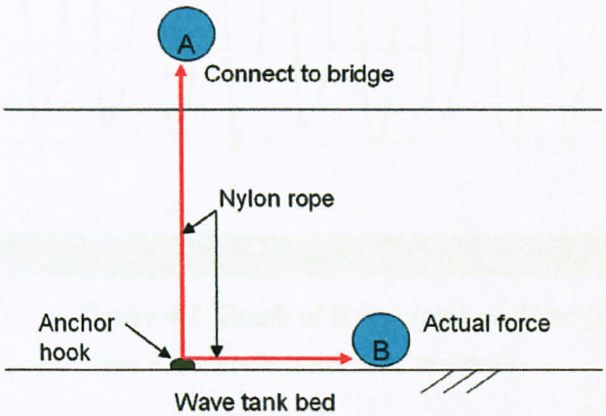


Figure 4.1: Layout of the Calibration Setup for Forces at Mooring Lines

Forces at the Mooring Line

One of the mooring lines is connected to the scale on the bridge to obtain the forces applied to the mooring line cause by the impact of wave and current to the structure. The experimental setup for the calibration is as above. Result is as below;

From hypothetical report; Maximum force = 597×10^3 N

From experimental result; Maximum force = 8.924 N (0.91 kg)

Based on Calibration Curve;

$y = 0.3923\,x - 1.628$

$8.924 = 0.3923x - 1.628$

Actual Force, $x = 26.9$ N

TEST NO		:	1
1.	Actual Wave Height (cm)	:	13
2.	Actual Wave Period (s)	:	5.08
3.	Maximum Heave Responses (cm)	:	16.5
4.	Maximum Surge Responses (cm)	:	17.4
5.	Maximum Tilting Angle	:	0°
6.	Current Velocity (m/s)	:	0

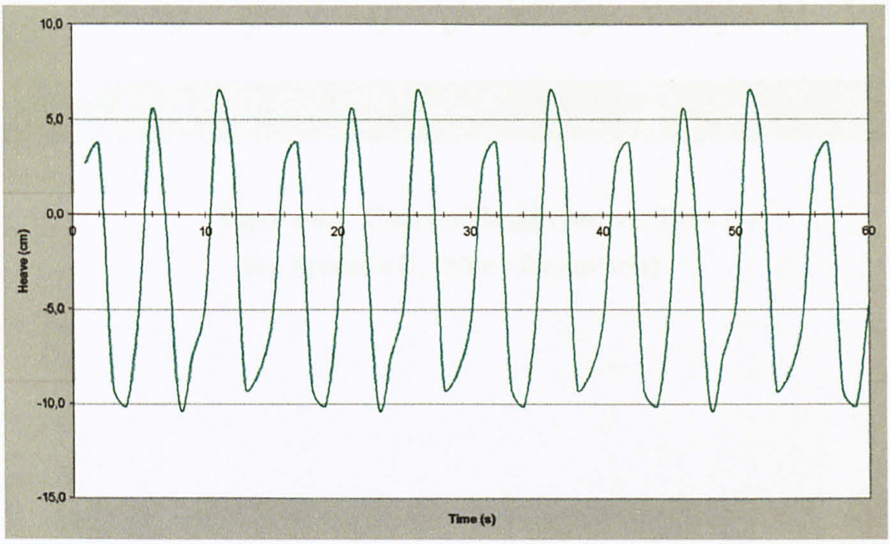


Figure 4.2: Graph of Heave (cm) vs. Time (s)

(See Appendix B; Table 1 for raw data)

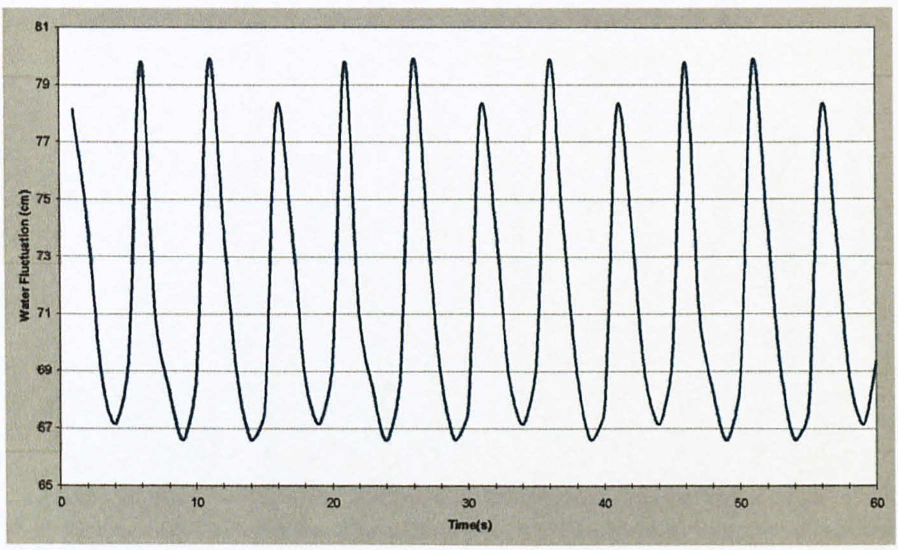


Figure 4.3: Graph of Water Fluctuation (cm) vs. Time (s)

(See Appendix B; Table 1 for raw data)

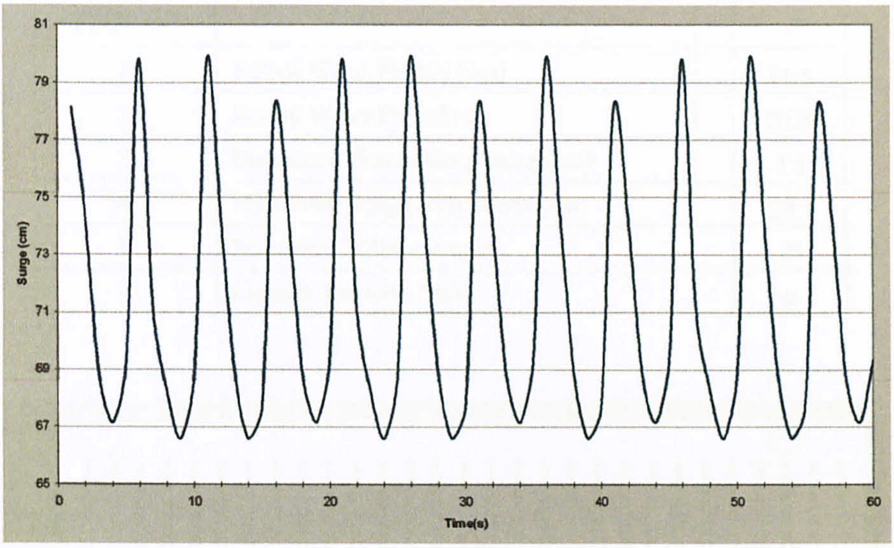


Figure 4.4: Graph of Surge (cm) vs. Time (s)

(See Appendix B; Table 1 for raw data)

TEST NO		:	2
1.	Actual Wave Height (cm)	:	11.5
2.	Actual Wave Period (s)	:	2.04
3.	Maximum Heave Responses (cm)	:	3.3
4.	Maximum Surge Responses (cm)	:	20.1
5.	Maximum Tilting Angle	:	5°
6.	Current Velocity (m/s)	:	0

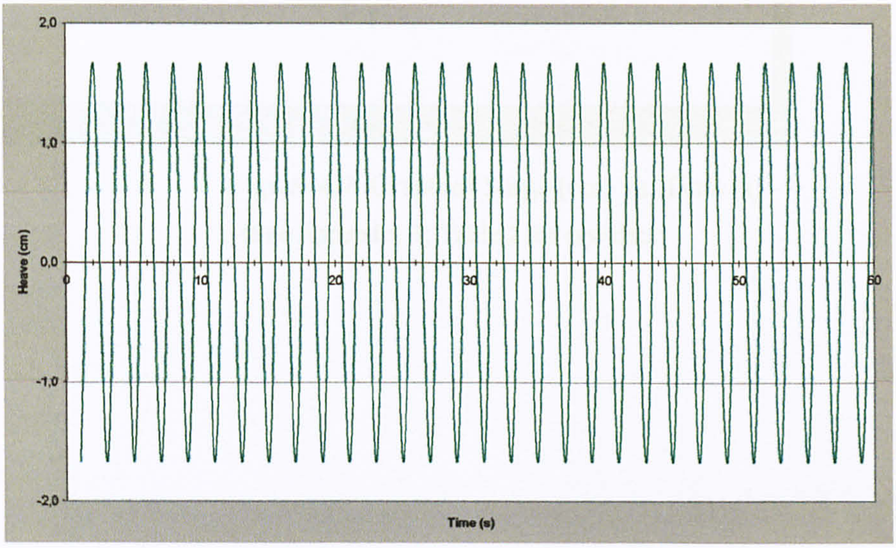


Figure 4.5: Graph of Heave (cm) vs. Time (s)

(See Appendix B; Table 2 for raw data)

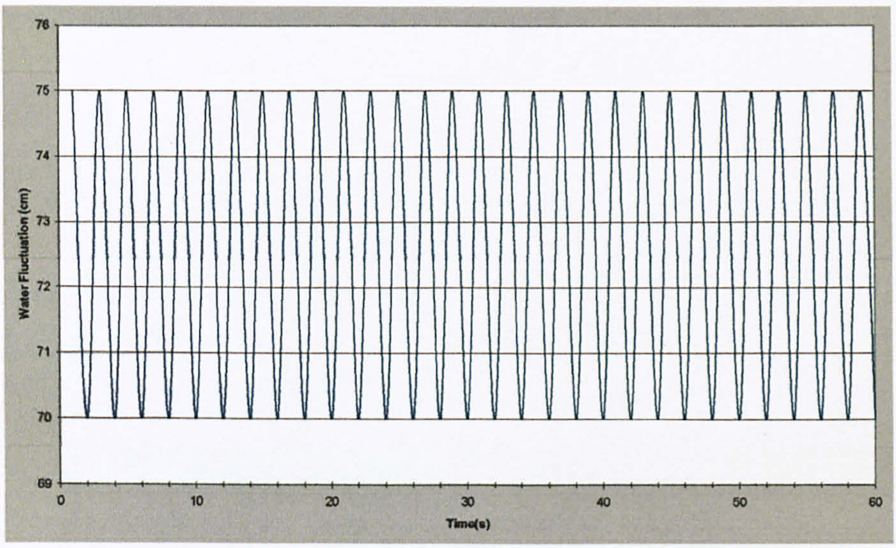


Figure 4.6: Graph of Water Fluctuation (cm) vs. Time (s)

(See Appendix B; Table 2 for raw data)

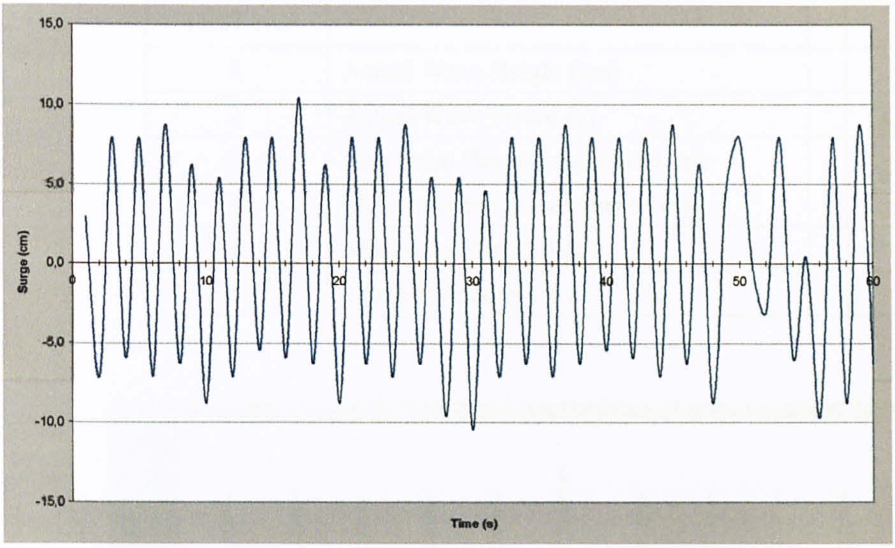


Figure 4.7: Graph of Surge (cm) vs. Time (s)
(See Appendix B; Table 2 for raw data)

TEST NO		:	3
1.	Actual Wave Height (cm)	:	22
2.	Actual Wave Period (s)	:	5,01
3.	Maximum Heave Responses (cm)	:	27,5
4.	Maximum Surge Responses (cm)	:	33,1
5.	Maximum Tilting Angle	:	11°
6.	Current Velocity (m/s)	:	0

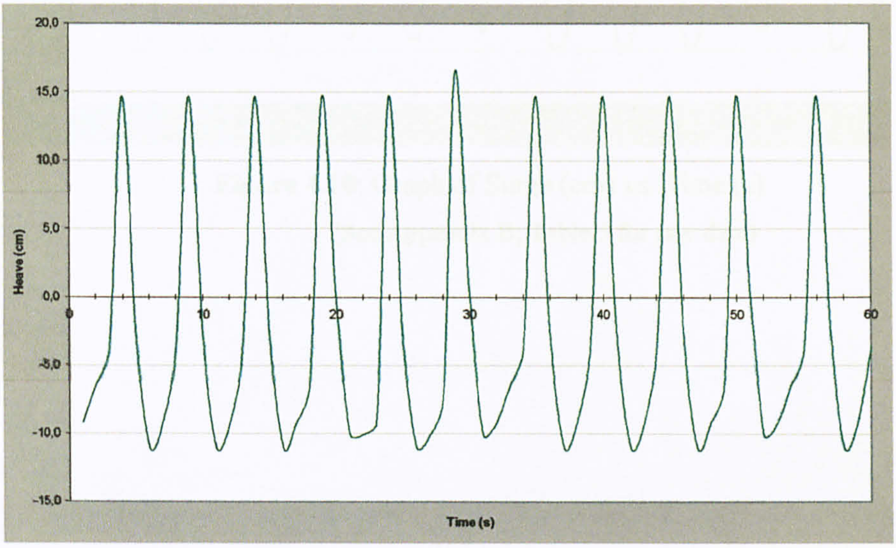


Figure 4.8: Graph of Heave (cm) vs. Time (s)

(See Appendix B; Table 3 for raw data)

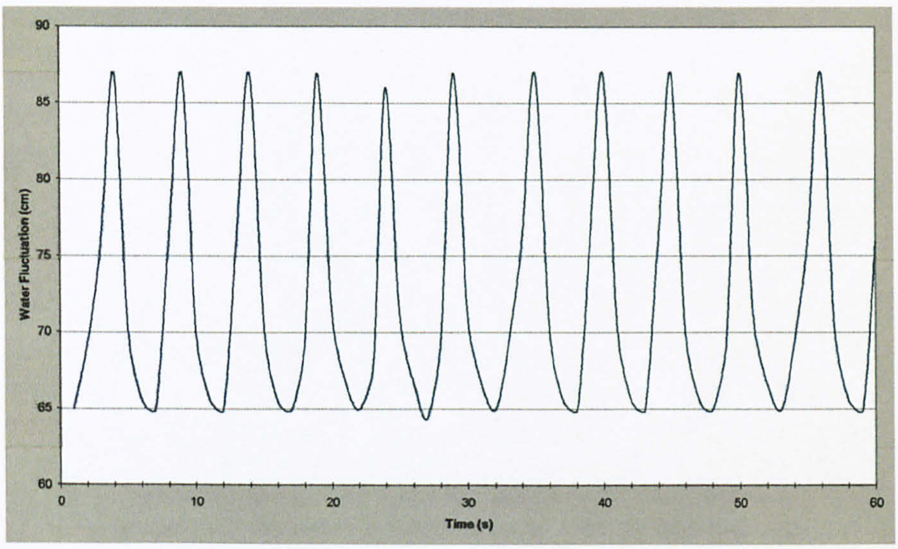


Figure 4.8: Graph of Water Fluctuation (cm) vs. Time (s)

(See Appendix B; Table 3 for raw data)

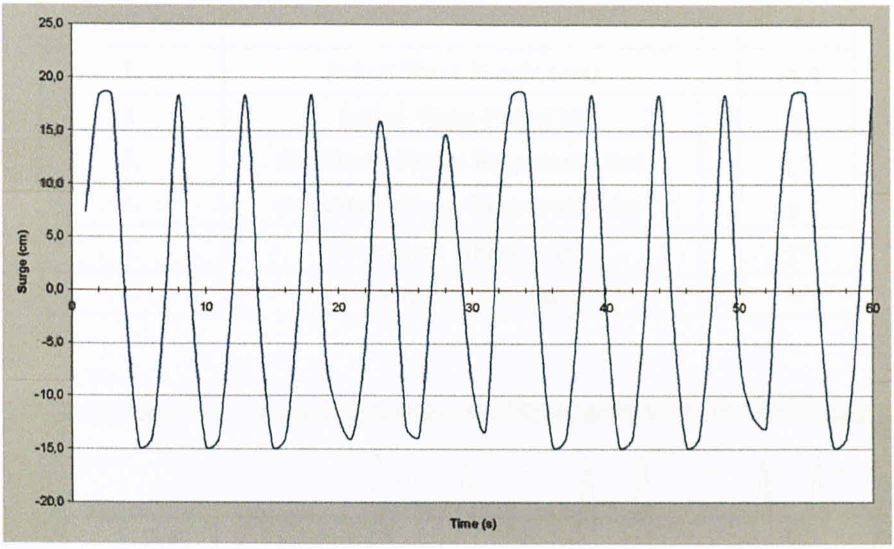


Figure 4.10: Graph of Surge (cm) vs. Time (s)

(See Appendix B; Table 3 for raw data)

TEST NO		:	4
1.	Actual Wave Height (cm)	:	19,5
2.	Actual Wave Period (s)	:	2
3.	Maximum Heave Responses (cm)	:	4,2
4.	Maximum Surge Responses (cm)	:	35,1
5.	Maximum Tilting Angle	:	8°
6.	Current Velocity (m/s)	:	0

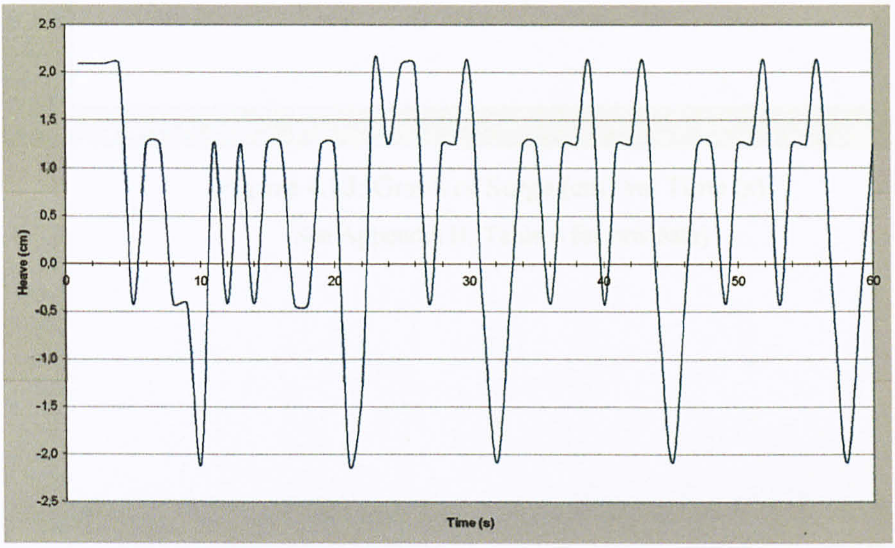


Figure 4.11: Graph of Heave (cm) vs. Time (s)

(See Appendix B; Table 4 for raw data)

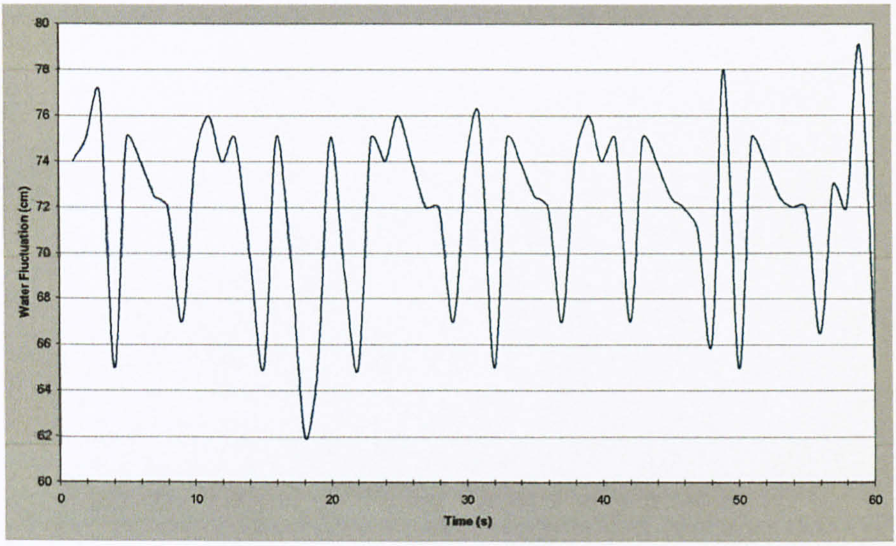


Figure 4.12: Graph of Water Fluctuation (cm) vs. Time (s)

(See Appendix B; Table 4 for raw data)

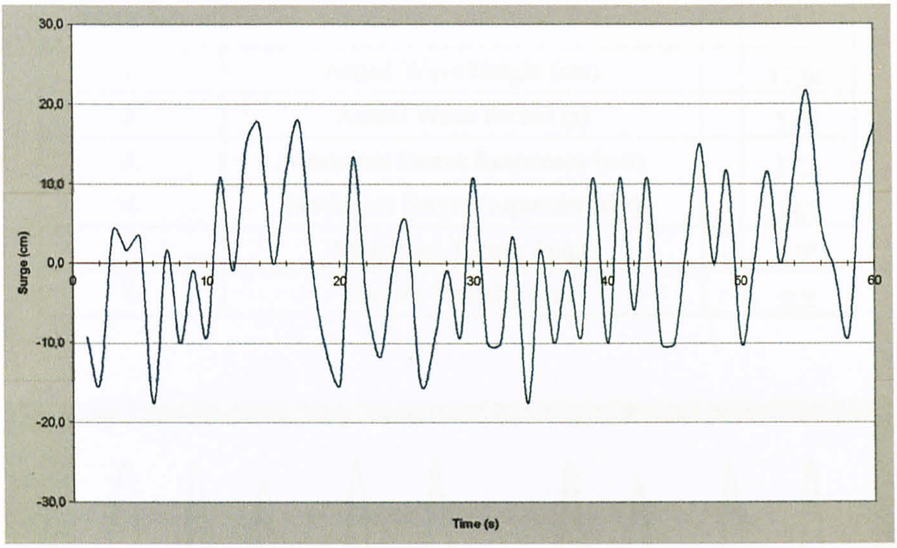


Figure 4.13: Graph of Surge (cm) vs. Time (s)

(See Appendix B; Table 4 for raw data)

TEST NO		:	5
1.	Actual Wave Height (cm)	:	12,65
2.	Actual Wave Period (s)	:	5,07
3.	Maximum Heave Responses (cm)	:	17,5
4.	Maximum Surge Responses (cm)	:	34,9
5.	Maximum Tilting Angle	:	10°
6.	Current Velocity (m/s)	:	0,2

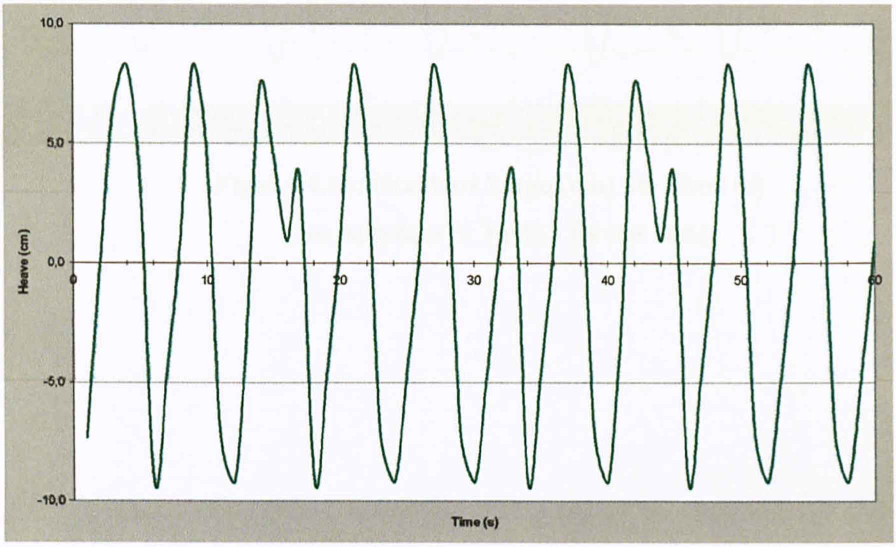


Figure 4.14: Graph of Heave (cm) vs. Time (s)

(See Appendix B; Table 5 for raw data)

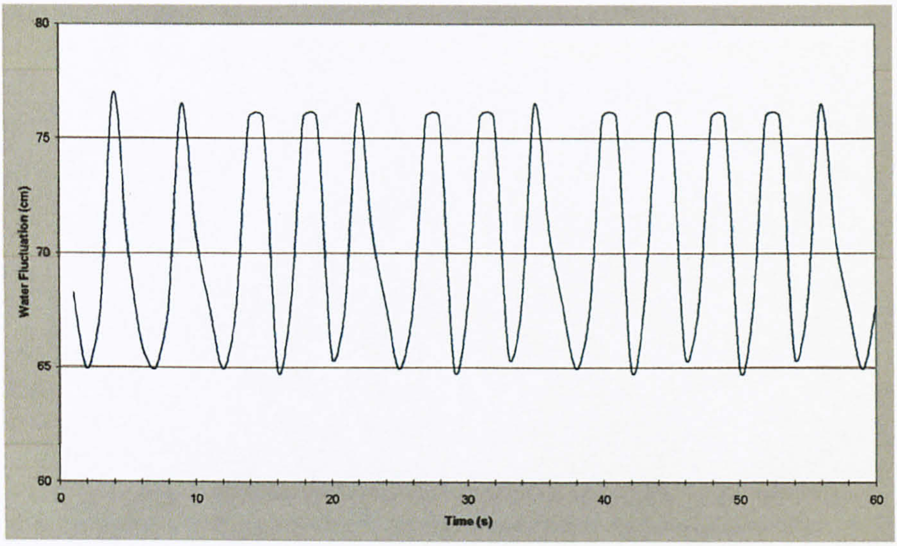


Figure 4.15: Graph of Water Fluctuation (cm) vs. Time (s)

(See Appendix B; Table 5 for raw data)

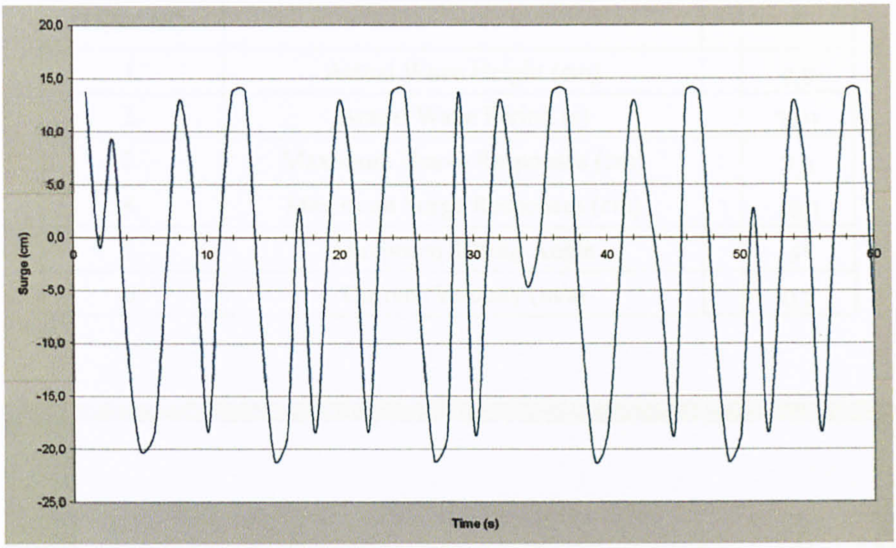


Figure 4.16: Graph of Surge (cm) vs. Time (s)

(See Appendix B; Table 5 for raw data)

TEST NO		:	6
1.	Actual Wave Height (cm)	:	9,9
2.	Actual Wave Period (s)	:	2,01
3.	Maximum Heave Responses (cm)	:	7,3
4.	Maximum Surge Responses (cm)	:	10,1
5.	Maximum Tilting Angle	:	5°
6.	Current Velocity (m/s)	:	0,2

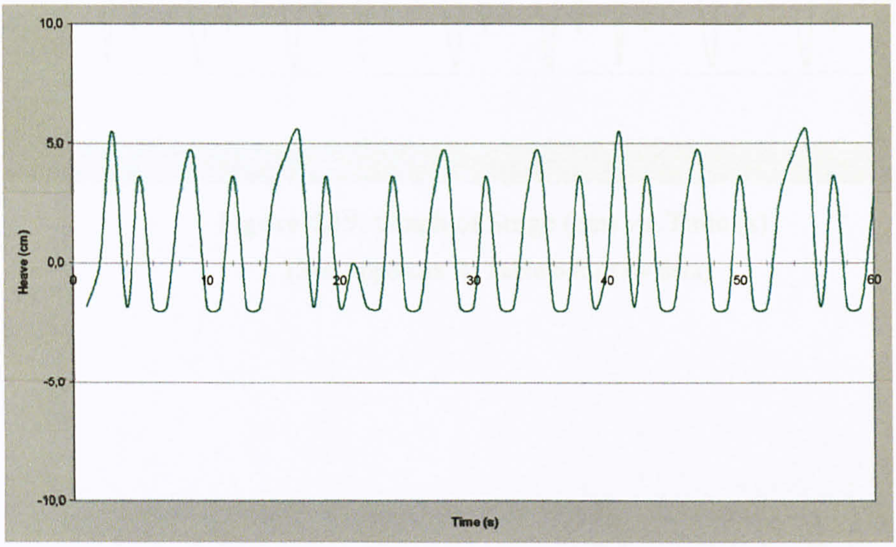


Figure 4.17: Graph of Heave (cm) vs. Time (s)
(See Appendix B; Table 6 for raw data)

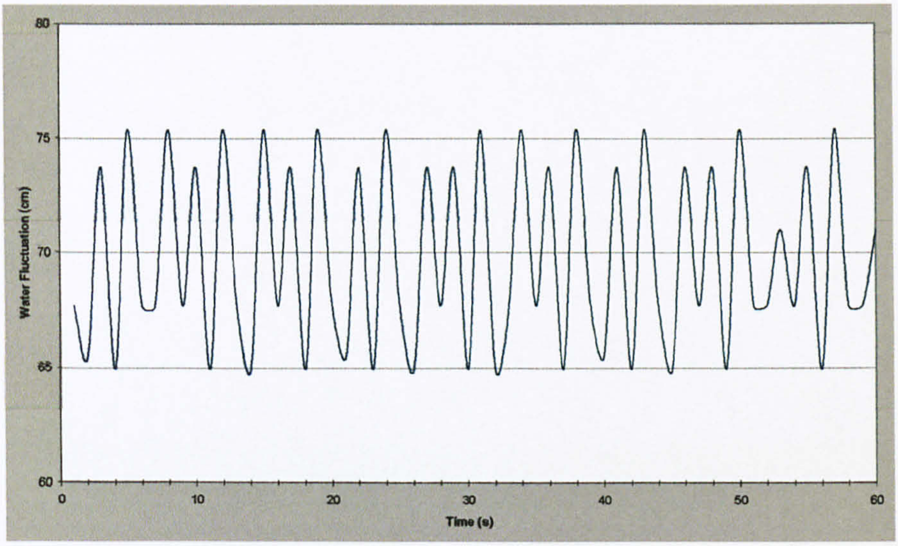


Figure 4.18: Graph of Water Fluctuation (cm) vs. Time (s)
(See Appendix B; Table 6 for raw data)

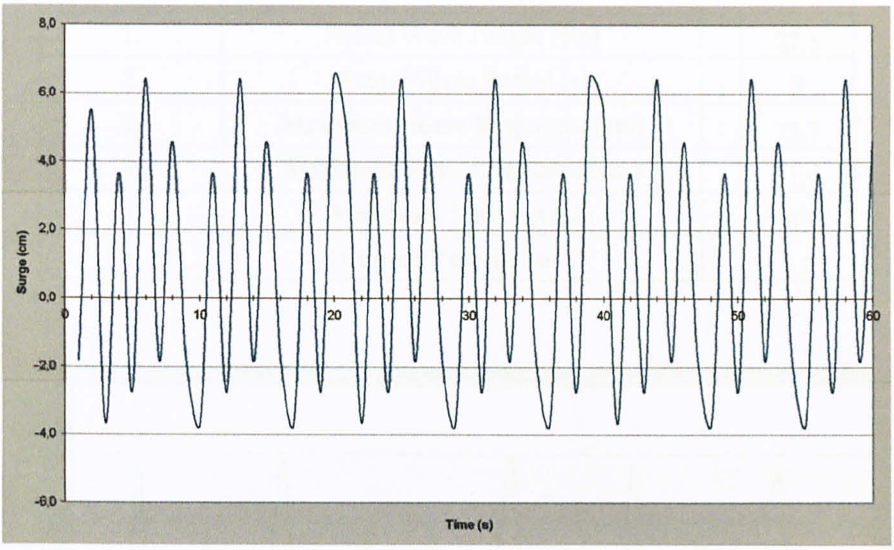


Figure 4.19: Graph of Surge (cm) vs. Time (s)

(See Appendix B; Table 6 for raw data)

TEST NO		:	7
1.	Actual Wave Height (cm)	:	27,5
2.	Actual Wave Period (s)	:	5
3.	Maximum Heave Responses (cm)	:	25,7
4.	Maximum Surge Responses (cm)	:	51,4
5.	Maximum Tilting Angle	:	8°
6.	Current Velocity (m/s)	:	0,2

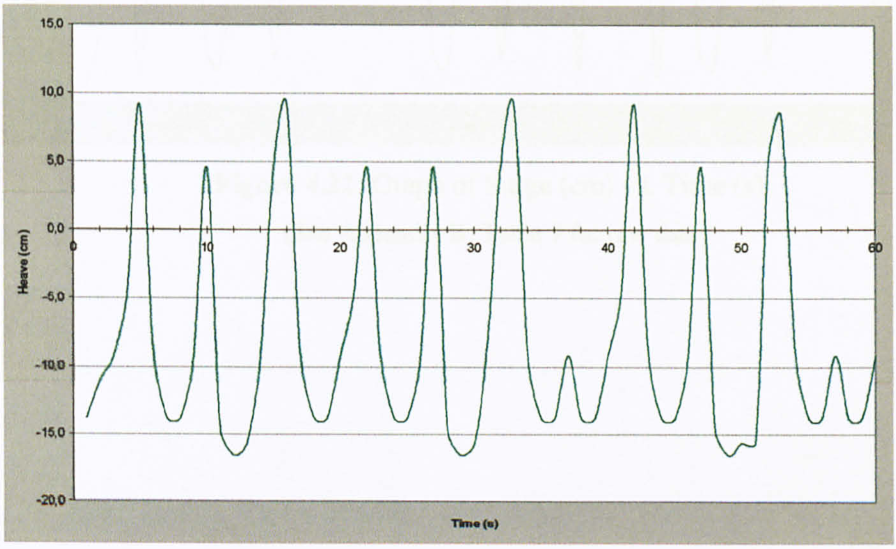


Figure 4.20: Graph of Heave (cm) vs. Time (s)

(See Appendix B; Table 7 for raw data)

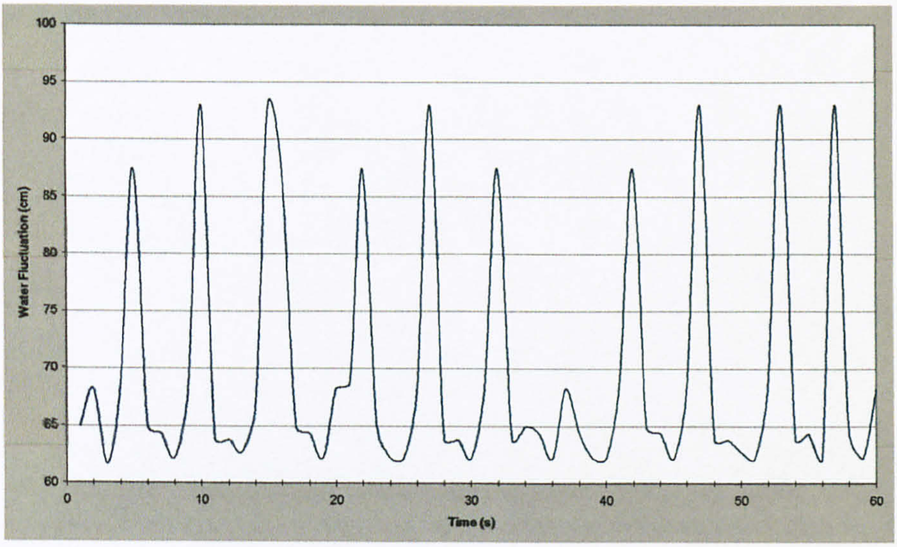


Figure 4.21: Graph of Water Fluctuation (cm) vs. Time (s)

(See Appendix B; Table 7 for raw data)

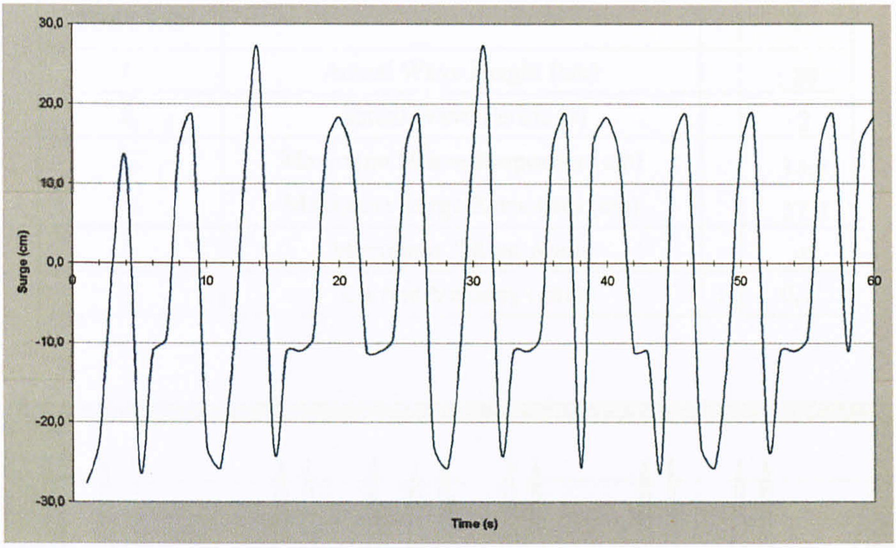


Figure 4.22: Graph of Surge (cm) vs. Time (s)
(See Appendix B; Table 7 for raw data)

TEST NO		:	8
1.	Actual Wave Height (cm)	:	: 20
2.	Actual Wave Period (s)	:	: 2
3.	Maximum Heave Responses (cm)	:	: 13,4
4.	Maximum Surge Responses (cm)	:	: 27,6
5.	Maximum Tilting Angle	:	: 4°
6.	Current Velocity (m/s)	:	0,2

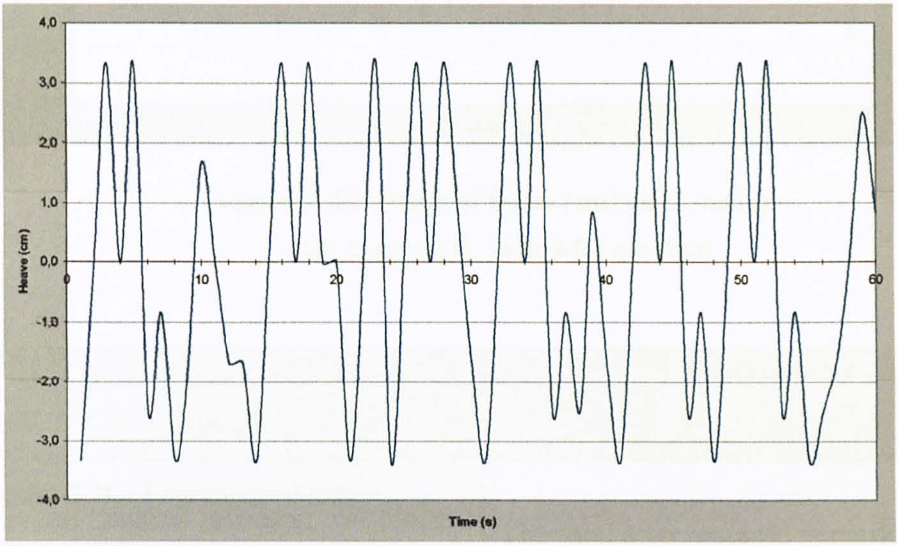


Figure 4.23: Graph of Heave (cm) vs. Time (s)

(See Appendix B; Table 8 for raw data)

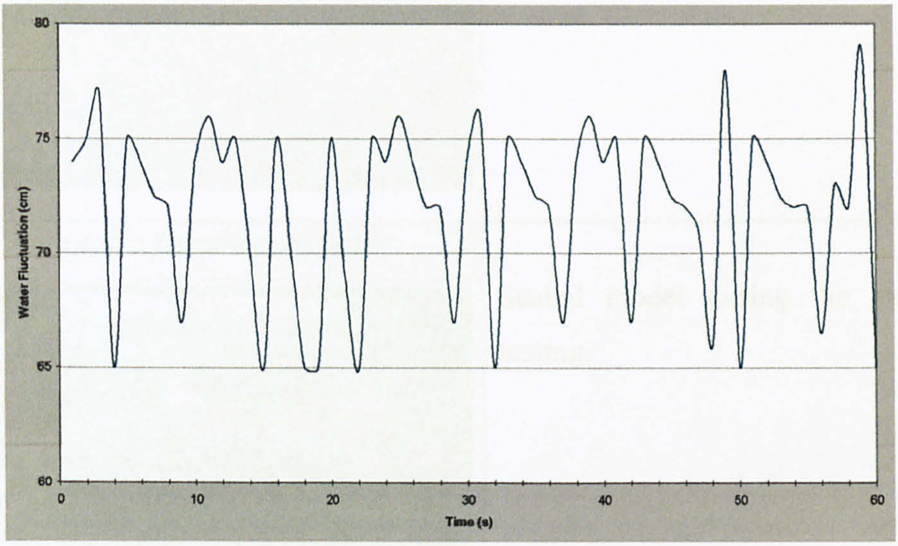


Figure 4.24: Graph of Water Fluctuation (cm) vs. Time (s)

(See Appendix B; Table 8 for raw data)

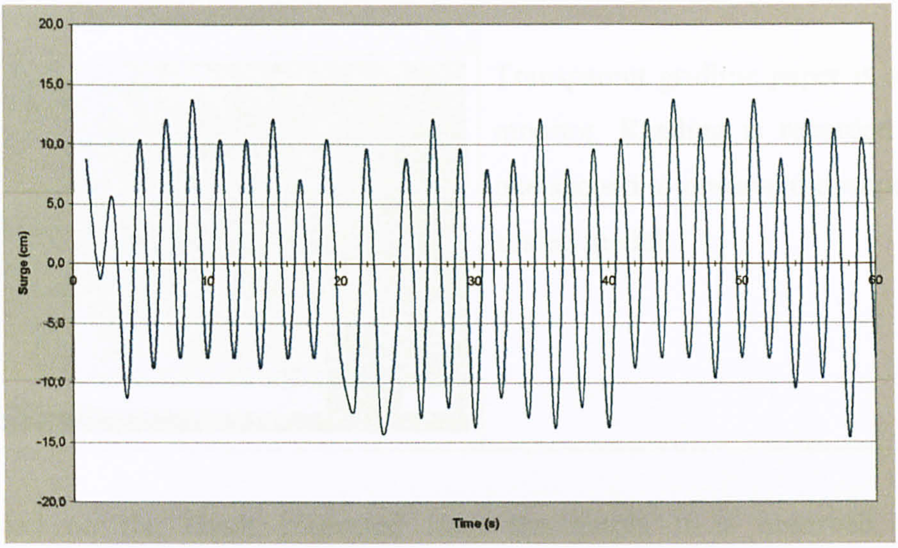


Figure 4.25: Graph of Surge (cm) vs. Time (s)

(See Appendix B; Table 8 for raw data)

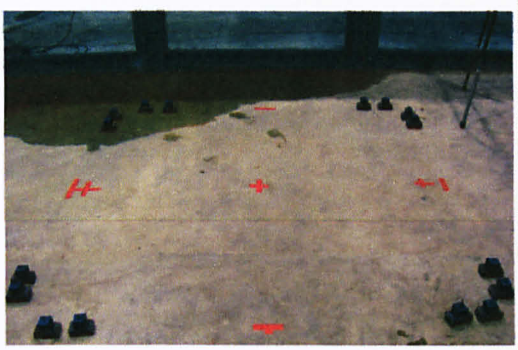
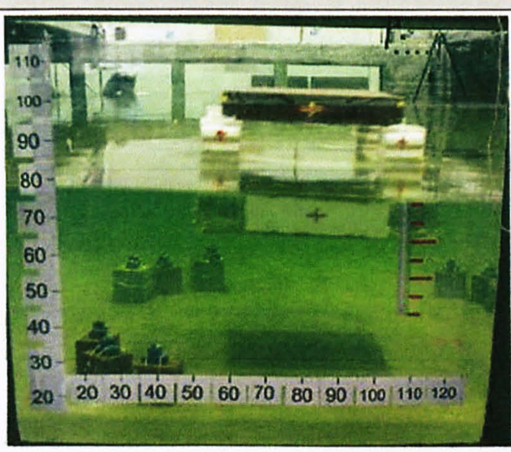
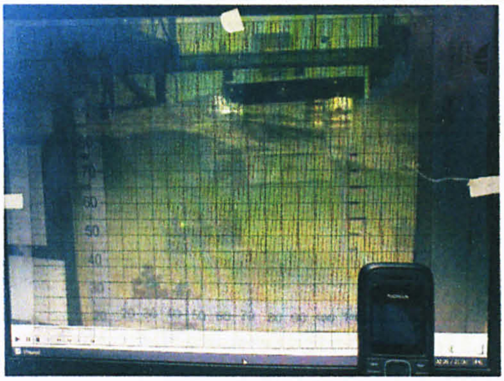
Figures	Descriptions
Figure 4.26 : Experimental Setup 	The total area required is mark to position the anchor and the model. Anchor is arranged according to the marked point.
Figure 4.27 : Experimental Setup 	Scaled model during the experimental testing.

Figure 4.28 : Data Analysis



Transparent gridline paper is stick to the monitor. Reading is recorded for every one second to observe the response of the scaled model.

Based on the result generated from the graph, it is observed that the displacement or motion of the structure is decreasing in the increasing of the wave frequency. As the wave frequency increases, the wave period is decreases, thus it took shorter wavelength that impact on the structure compared to the length of the structure. Both of the conditions are applied to displacement in y-axis and z-axis for regular type of wave. Whilst, for the displacement in x-axis direction is observed that the motion does not give any significant number since the structure is only subjected to regular type of wave.

However, there will be some calibration required to be done before the experiment take place. The position of the camera must be inline with the reference point. Measurement of the axis needs to be mark clearly in order to get the exact number of movement during the data collection later.

During the video capturing process, there are two cameras needed to capture the three dimensional axis of movement, thus at least two person are required to handle the camera to ensure that the data of the first camera is tally with the second one. Both operators of the camera can not synchronically record on the exactly same second of recording time.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.0 CONCLUSION AND RECOMMENDATION

In general, the semi-submersible has been and will continue to be the workhorse of the industry for rough, deepwater exploration. Although there are always restriction on an environmental conditions changes and variation from area to area and to use the most stringent requirements will be a cost burden that is not required.

It is highlighted that the wave and wind are the main root in verify the performance of semi-submersible hydrodynamic motion and loading reaction upon the six degree of motion reaction. And the main focus of wind and wave impact on the structure is the forces acting to the mooring lines. Mooring will experiences most of the forces due to the wave motion on the surface of the water. The test will be based on how much forces are encounter by the mooring lines through out when subjected to various types of wave motion.

In the future, an upgrading of the scaled model can be made in order to generate more accurate and exact result of the hydrodynamics stability of the semi-submersible platform. The variation in the distribution of weight on the topside can be carried out to check for the stability and to observe the motion of the structure when subjected to regular and irregular types of waves. Thus, the effect of severe impact condition to the structure will be measured to check for the possibility of tilting effect.

6.0 REFERENCES

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4. C.A Bainbridge, February 1984. *Design Consideration of Permanently Moored Semi-submersibles*, M.SC. C.Eng. M.R.Ae.S, Singapore

5. Subrata K.Chakrabarti .1994, Handbook of Offshore Engineering, (Volume I) Offshore Structure Analysis, Inc, Plainfield, Illinois, USA

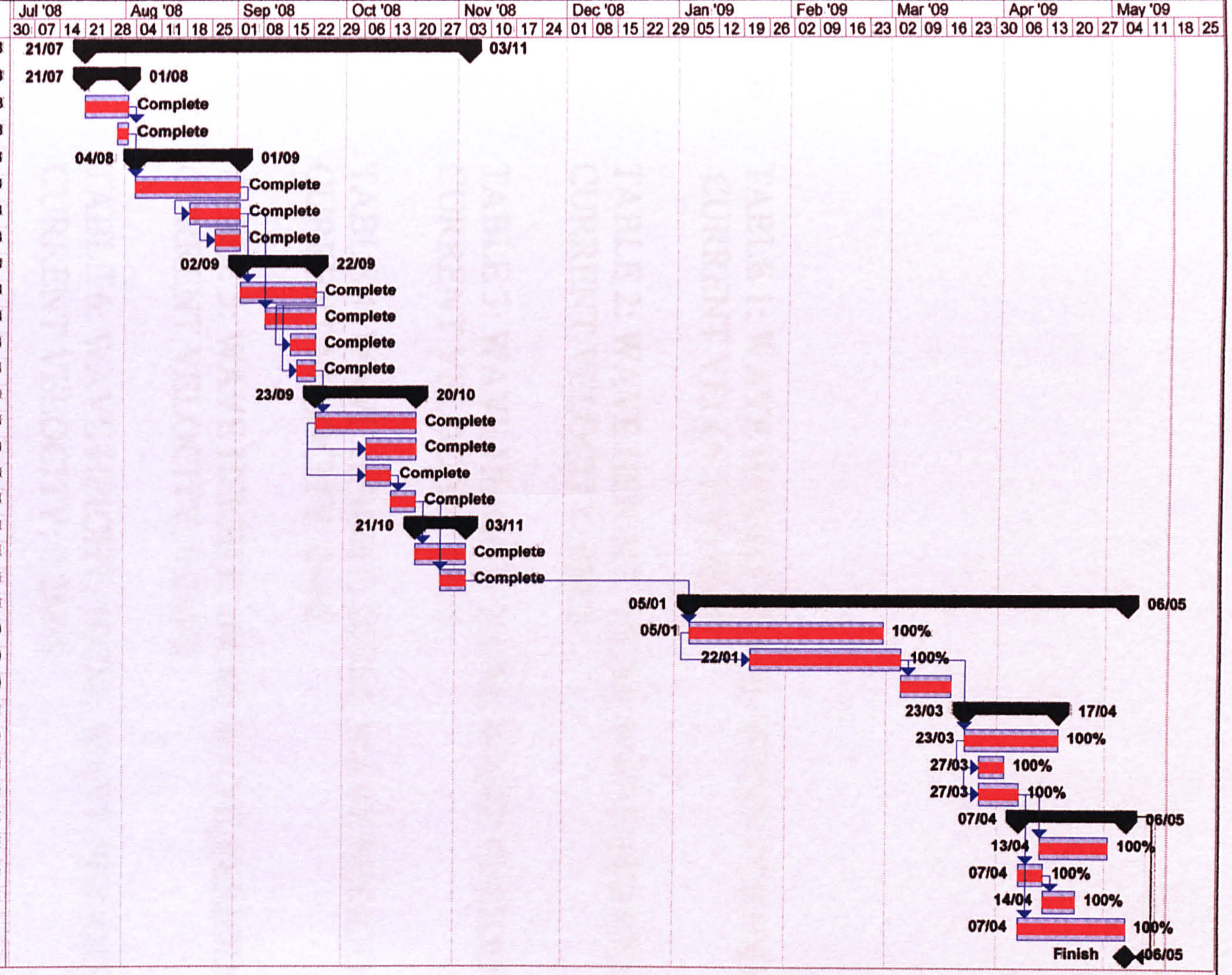
6. American Petroleum Institute: 'Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms', API RP2A-WSD, 21st Edition, December 2000.

7. American Institute of Steel Construction, Inc. (AISC) "Specification for the design, Fabrication, and erection of Structural Steel for Building", 9^{th} Edition.

LIST OF APPENDIX

A GANTT CHART

ID		Task Name	Duration	Start
1	✓	**FYP1**	**76 days**	**Mon 21/07/08**
2	✓	**Propose**	**10 days**	**Mon 21/07/08**
3	✓	Initiation of proposal	10 days	Mon 21/07/08
4	✓	Acceptance of proposal	3 days	Wed 30/07/08
5	✓	**Prelits**	**21 days**	**Mon 04/08/08**
6	✓	Preliminary Literature Search	21 days	Mon 04/08/08
7	✓	Preliminary Data Collection	10 days	Tue 19/08/08
8	✓	Combined Prelim and Progress Re	5 days	Tue 26/08/08
9	✓	**Design**	**15 days**	**Tue 02/09/08**
10	✓	Preliminary Design	15 days	Tue 02/09/08
11	✓	Design of Model Test	10 days	Tue 09/09/08
12	✓	Scaling Laws	5 days	Tue 16/09/08
13	✓	Model Parameters	3 days	Thu 18/09/08
14	✓	**Detail**	**20 days**	**Tue 23/09/08**
15	✓	Detailed Design	20 days	Tue 23/09/08
16	✓	Model Construction	10 days	Tue 07/10/08
17	✓	Model Calibration	5 days	Tue 07/10/08
18	✓	Preliminary Test	5 days	Tue 14/10/08
19	✓	**Report**	**10 days**	**Tue 21/10/08**
20	✓	FYP 1 Interim report	10 days	Tue 21/10/08
21	✓	FYP 1 Final Presentation	5 days	Tue 28/10/08
22		**FYP2**	**88 days**	**Mon 05/01/09**
23	✓	Modification of Model	40 days	Mon 05/01/09
24	✓	Supplementary Test	30 days	Thu 22/01/09
25	✓	Combined Progress Report	10 days	Thu 05/03/09
26	✓	**Test**	**20 days**	**Mon 23/03/09**
27	✓	In-place Calibration	20 days	Mon 23/03/09
28	✓	Test Run	5 days	Fri 27/03/09
29	✓	Data evaluation and comparison	7 days	Fri 27/03/09
30	✓	**Final Report**	**22 days**	**Tue 07/04/09**
31	✓	Prepare draft report	15 days	Mon 13/04/09
32	✓	Poster Presentation	5 days	Tue 07/04/09
33	✓	FYP2 Final Presentation	7 days	Tue 14/04/09
34	✓	Prepare Final Dissertation Report	22 days	Tue 07/04/09
35		Finish	0 days	Wed 06/05/09



Name: Ainor Syafarizan Bt Mohamad Yusof
ID: 8564
Date: Mon 18/05/09

Task		Milestone		External Tasks	
Split		Summary		External Milestone	
Progress		Project Summary		Deadline	

B TABLE 1: WAVE HEIGHT: 10CM; WAVE PERIOD: 5S; CURRENT VELOCITY: 0M/S

TABLE 2: WAVE HEIGHT: 10CM; WAVE PERIOD: 2S; CURRENT VELOCITY: 0M/S

TABLE 3: WAVE HEIGHT: 20CM; WAVE PERIOD: 5S; CURRENT VELOCITY: 0M/S

TABLE 4: WAVE HEIGHT: 20CM; WAVE PERIOD: 2S; CURRENT VELOCITY: 0M/S

TABLE 5: WAVE HEIGHT: 10CM; WAVE PERIOD: 5S; CURRENT VELOCITY: 0.2M/S

TABLE 6: WAVE HEIGHT: 10CM; WAVE PERIOD: 2S; CURRENT VELOCITY: 0.2M/S

TABLE 7: WAVE HEIGHT: 20CM; WAVE PERIOD: 5S; CURRENT VELOCITY: 0.2M/S

TABLE 8: WAVE HEIGHT: 20CM; WAVE PERIOD: 2S; CURRENT VELOCITY: 0.2M/S

RESULT.

TEST NO: **1**

1 Actual Wave Height (cm) : 13

2 Actual Wave Period (s) : 5,08

3 Maximum Heave Responses (cm) : 16,5

4 Maximum Surge Responses (cm) : 17,4

5 Maximum Tilting Angle : 0

6 Current Velocity : 0

7 Responses

(TIME,s)	HEAVE (cm)	SURGE (cm)	WATER(cm)	(TIME,s)	HEAVE (cm)	SURGE (cm)	WATER(cm)	(TIME,s)	HEAVE (cm)	SURGE (cm)	WATER(cm)
1	1,65	3,3	78,15	21	3,3	1,65	79,8	41	1,65	3,3	78,15
2	2,2	-4,4	74,3	22	0	-6,05	71	42	2,2	-4,4	74,3
3	-5,5	-6,6	68,8	23	-6,05	-5,5	68,25	43	-5,5	-6,05	68,8
4	-6,05	-3,3	67,15	24	-4,4	-2,2	66,6	44	-6,05	-3,3	67,15
5	-2,75	3,85	69,35	25	-2,75	3,3	68,8	45	-2,75	3,85	69,35
6	3,3	1,65	79,8	26	3,85	1,1	79,8	46	3,3	1,65	79,8
7	0	-6,05	71	27	2,2	-4,95	74,3	47	0	-6,05	71
8	-6,05	-5,5	68,25	28	-5,5	-6,05	68,8	48	-6,05	-5,5	68,25
9	-4,4	-2,2	66,6	29	-4,95	-1,65	66,6	49	-4,4	-2,2	66,6
10	-2,75	3,3	68,8	30	-3,3	2,75	67,7	50	-2,75	3,3	68,8
11	3,85	1,1	79,8	31	1,65	3,3	78,15	51	3,85	1,1	79,8
12	2,2	-4,95	74,3	32	2,2	-4,4	74,3	52	2,2	-4,95	74,3
13	-5,5	-6,05	68,8	33	-5,5	-6,05	68,8	53	-5,5	-6,05	68,8
14	-4,95	-1,65	66,6	34	-6,05	-3,3	67,15	54	-4,95	-1,65	66,6
15	-3,3	2,75	67,7	35	-2,75	3,85	69,35	55	-3,3	2,75	67,7
16	1,65	3,3	78,15	36	3,85	1,1	79,8	56	1,65	3,3	78,15
17	2,2	-4,4	74,3	37	2,2	-4,95	74,3	57	2,2	-4,4	74,3
18	-5,5	-6,05	68,8	38	-5,5	-6,05	68,8	58	-5,5	-6,05	68,8
19	-6,05	-3,3	67,15	39	-4,95	-1,65	66,6	59	-6,05	-3,3	67,15
20	-2,75	3,85	69,35	40	-3,3	2,75	67,7	60	-2,75	3,85	69,35

CORRECTED VALUE

(TIME,s)	HEAVE (cm)	SURGE (cm)	WATER(cm)	(TIME,s)	HEAVE (cm)	SURGE (cm)	WATER(cm)	(TIME,s)	HEAVE (cm)	SURGE (cm)	WATER(cm)
1	2,8	5,5	78,15	21	5,5	2,8	79,8	41	2,8	5,5	78,15
2	3,7	-7,3	74,3	22	0,0	-10,1	71	42	3,7	-7,3	74,3
3	-9,2	-11,0	68,8	23	-10,1	-9,2	68,25	43	-9,2	-10,1	68,8
4	-10,1	-5,5	67,15	24	-7,3	-3,7	66,6	44	-10,1	-5,5	67,15
5	-4,6	6,4	69,35	25	-4,6	5,5	68,8	45	-4,6	6,4	69,35
6	5,5	2,8	79,8	26	6,4	1,8	79,8	46	5,5	2,8	79,8
7	0,0	-10,1	71	27	3,7	-8,3	74,3	47	0,0	-10,1	71
8	-10,1	-9,2	68,25	28	-9,2	-10,1	68,8	48	-10,1	-9,2	68,25
9	-7,3	-3,7	66,6	29	-8,3	-2,8	66,6	49	-7,3	-3,7	66,6
10	-4,6	5,5	68,8	30	-5,5	4,6	67,7	50	-4,6	5,5	68,8
11	6,4	1,8	79,8	31	2,8	5,5	78,15	51	6,4	1,8	79,8
12	3,7	-8,3	74,3	32	3,7	-7,3	74,3	52	3,7	-8,3	74,3
13	-9,2	-10,1	68,8	33	-9,2	-10,1	68,8	53	-9,2	-10,1	68,8
14	-8,3	-2,8	66,6	34	-10,1	-5,5	67,15	54	-8,3	-2,8	66,6
15	-5,5	4,6	67,7	35	-4,6	6,4	69,35	55	-5,5	4,6	67,7
16	2,8	5,5	78,15	36	6,4	1,8	79,8	56	2,8	5,5	78,15
17	3,7	-7,3	74,3	37	3,7	-8,3	74,3	57	3,7	-7,3	74,3
18	-9,2	-10,1	68,8	38	-9,2	-10,1	68,8	58	-9,2	-10,1	68,8
19	-10,1	-5,5	67,15	39	-8,3	-2,8	66,6	59	-10,1	-5,5	67,15
20	-4,6	6,4	69,35	40	-5,5	4,6	67,7	60	-4,6	6,4	69,35

RESULT.

TEST NO: **2**

1 Actual Wave Height (cm) : 11.5
2 Actual Wave Period (s) : 2.04
3 Maximum Heave Responses (cm) : 3.3
4 Maximum Surge Responses (cm) : 20.1
5 Maximum Tilting Angle : 5
6 Responses

(TIME,s)	HEAVE (cm)	SURGE (cm)	WATER(cm)	(TIME,s)	HEAVE (cm)	SURGE (cm)	WATER(cm)	(TIME,s)	HEAVE (cm)	SURGE (cm)	WATER(cm)
1	-1	1,75	75	21	-1	4,75	75	41	-1	4,75	75
2	1	-4,25	70	22	1	-3,75	70	42	1	-3,55	70
3	-1	4,75	75	23	-1	4,75	75	43	-1	4,75	75
4	1	-3,55	70	24	1	-4,25	70	44	1	-4,25	70
5	-1	4,75	75	25	-1	5,25	75	45	-1	5,25	75
6	1	-4,25	70	26	1	-3,75	70	46	1	-3,75	70
7	-1	5,25	75	27	-1	3,25	75	47	-1	3,75	75
8	1	-3,75	70	28	1	-5,75	70	48	1	-5,25	70
9	-1	3,75	75	29	-1	3,25	75	49	-1	2,75	75
10	1	-5,25	70	30	1	-6,25	70	50	1	4,75	70
11	-1	3,25	75	31	-1	2,75	75	51	-1	-0,25	75
12	1	-4,25	70	32	1	-4,25	70	52	1	-1,75	70
13	-1	4,75	75	33	-1	4,75	75	53	-1	4,75	75
14	1	-3,25	70	34	1	-3,75	70	54	1	-3,55	70
15	-1	4,75	75	35	-1	4,75	75	55	-1	0,25	75
16	1	-3,55	70	36	1	-4,25	70	56	1	-5,75	70
17	-1	6,25	75	37	-1	5,25	75	57	-1	4,75	75
18	1	-3,75	70	38	1	-3,75	70	58	1	-5,25	70
19	-1	3,75	75	39	-1	4,75	75	59	-1	5,25	75
20	1	-5,25	70	40	1	-3,25	70	60	1	-3,75	70

CORRECTED VALUE

(TIME,s)	HEAVE (cm)	SURGE (cm)	WATER(cm)	(TIME,s)	HEAVE (cm)	SURGE (cm)	WATER(cm)	(TIME,s)	HEAVE (cm)	SURGE (cm)	WATER(cm)
1	-1,7	2,9	75	21	-1,7	7,9	75	41	-1,7	7,9	75
2	1,7	-7,1	70	22	1,7	-6,3	70	42	1,7	-5,9	70
3	-1,7	7,9	75	23	-1,7	7,9	75	43	-1,7	7,9	75
4	1,7	-5,9	70	24	1,7	-7,1	70	44	1,7	-7,1	70
5	-1,7	7,9	75	25	-1,7	8,8	75	45	-1,7	8,8	75
6	1,7	-7,1	70	26	1,7	-6,3	70	46	1,7	-6,3	70
7	-1,7	8,8	75	27	-1,7	5,4	75	47	-1,7	6,3	75
8	1,7	-6,3	70	28	1,7	-9,6	70	48	1,7	-8,8	70
9	-1,7	6,3	75	29	-1,7	5,4	75	49	-1,7	4,6	75
10	1,7	-8,8	70	30	1,7	-10,4	70	50	1,7	7,9	70
11	-1,7	5,4	75	31	-1,7	4,6	75	51	-1,7	-0,4	75
12	1,7	-7,1	70	32	1,7	-7,1	70	52	1,7	-2,9	70
13	-1,7	7,9	75	33	-1,7	7,9	75	53	-1,7	7,9	75
14	1,7	-5,4	70	34	1,7	-6,3	70	54	1,7	-5,9	70
15	-1,7	7,9	75	35	-1,7	7,9	75	55	-1,7	0,4	75
16	1,7	-5,9	70	36	1,7	-7,1	70	56	1,7	-9,6	70
17	-1,7	10,4	75	37	-1,7	8,8	75	57	-1,7	7,9	75
18	1,7	-6,3	70	38	1,7	-6,3	70	58	1,7	-8,8	70
19	-1,7	6,3	75	39	-1,7	7,9	75	59	-1,7	8,8	75
20	1,7	-8,8	70	40	1,7	-5,4	70	60	1,7	-6,3	70

RESULT.

TEST NO: **3**

1 Actual Wave Height (cm) : 22

2 Actual Wave Period (s) : 5,01

3 Maximum Heave Responses (cm) : 27,5

4 Maximum Surge Responses (cm) : 33,1

5 Maximum Tilting Angle : 11

6 Current Velocity : 0

7 Responses

(TIME,s)	HEAVE (cm)	SURGE (cm)	WATER(cm)	(TIME,s)	HEAVE (cm)	SURGE (cm)	WATER(cm)	(TIME,s)	HEAVE (cm)	SURGE (cm)	WATER(cm)
1	-5,5	4,4	64,95	21	-6,05	-8,25	66,6	41	-1,65	-8,8	69,9
2	-3,85	11	69,35	22	-6,05	-2,75	64,95	42	-6,6	-8,25	65,5
3	-2,2	11	75,95	23	-5,5	9,35	67,7	43	-5,5	0	64,95
4	8,8	-1,1	86,95	24	8,8	4,4	86	44	-2,2	11	75,95
5	-1,65	-8,8	69,9	25	-1,65	-7,7	71	45	8,8	-1,1	86,95
6	-6,6	-8,25	65,5	26	-6,6	-8,25	66,6	46	-1,65	-8,8	69,9
7	-5,5	0	64,95	27	-6,05	0,55	64,4	47	-6,6	-8,25	65,5
8	-2,2	11	75,95	28	-4,4	8,8	69,35	48	-5,5	0	64,95
9	8,8	-1,1	86,95	29	9,9	2,2	86,95	49	-3,85	11	69,35
10	-1,65	-8,8	69,9	30	0	-5,5	71	50	8,8	-3,85	86,95
11	-6,6	-8,25	65,5	31	-6,05	-7,7	66,6	51	0	-7,15	71
12	-5,5	0	64,95	32	-5,5	4,4	64,95	52	-6,05	-7,7	66,6
13	-2,2	11	75,95	33	-3,85	11	69,35	53	-5,5	4,4	64,95
14	8,8	-1,1	86,95	34	-2,2	11	75,95	54	-3,85	11	69,35
15	-1,65	-8,8	69,9	35	8,8	-1,1	86,95	55	-2,2	11	75,95
16	-6,6	-8,25	65,5	36	-1,65	-8,8	69,9	56	8,8	-1,1	86,95
17	-5,5	0	64,95	37	-6,6	-8,25	65,5	57	-1,65	-8,8	69,9
18	-3,85	11	69,35	38	-5,5	0	64,95	58	-6,6	-8,25	65,5
19	8,8	-3,85	86,95	39	-2,2	11	75,95	59	-5,5	0	64,95
20	0	-7,15	71	40	8,8	-1,1	86,95	60	-2,2	11	75,95

CORRECTED VALUE

(TIME,s)	HEAVE (cm)	SURGE (cm)	WATER(cm)	(TIME,s)	HEAVE (cm)	SURGE (cm)	WATER(cm)	(TIME,s)	HEAVE (cm)	SURGE (cm)	WATER(cm)
1	-9,2	7,3	64,95	21	-10,1	-13,8	66,6	41	-2,8	-14,7	69,9
2	-6,4	18,4	69,35	22	-10,1	-4,6	64,95	42	-11,0	-13,8	65,5
3	-3,7	18,4	75,95	23	-9,2	15,6	67,7	43	-9,2	0,0	64,95
4	14,7	-1,8	86,95	24	14,7	7,3	86	44	-3,7	18,4	75,95
5	-2,8	-14,7	69,9	25	-2,8	-12,9	71	45	14,7	-1,8	86,95
6	-11,0	-13,8	65,5	26	-11,0	-13,8	66,6	46	-2,8	-14,7	69,9
7	-9,2	0,0	64,95	27	-10,1	0,9	64,4	47	-11,0	-13,8	65,5
8	-3,7	18,4	75,95	28	-7,3	14,7	69,35	48	-9,2	0,0	64,95
9	14,7	-1,8	86,95	29	16,5	3,7	86,95	49	-6,4	18,4	69,35
10	-2,8	-14,7	69,9	30	0,0	-9,2	71	50	14,7	-6,4	86,95
11	-11,0	-13,8	65,5	31	-10,1	-12,9	66,6	51	0,0	-11,9	71
12	-9,2	0,0	64,95	32	-9,2	7,3	64,95	52	-10,1	-12,9	66,6
13	-3,7	18,4	75,95	33	-6,4	18,4	69,35	53	-9,2	7,3	64,95
14	14,7	-1,8	86,95	34	-3,7	18,4	75,95	54	-6,4	18,4	69,35
15	-2,8	-14,7	69,9	35	14,7	-1,8	86,95	55	-3,7	18,4	75,95
16	-11,0	-13,8	65,5	36	-2,8	-14,7	69,9	56	14,7	-1,8	86,95
17	-9,2	0,0	64,95	37	-11,0	-13,8	65,5	57	-2,8	-14,7	69,9
18	-6,4	18,4	69,35	38	-9,2	0,0	64,95	58	-11,0	-13,8	65,5
19	14,7	-6,4	86,95	39	-3,7	18,4	75,95	59	-9,2	0,0	64,95
20	0,0	-11,9	71	40	14,7	-1,8	86,95	60	-3,7	18,4	75,95

RESULT.

TEST NO: **4**

1 Actual Wave Height (cm) : 19,5

2 Actual Wave Period (s) : 2

3 Maximum Heave Responses (cm) : 4,2

4 Maximum Surge Responses (cm) : 35,1

5 Maximum Tilting Angle : 8

6 Responses

(TIME,s)	HEAVE (cm)	SURGE (cm)	WATER(cm)	(TIME,s)	HEAVE (cm)	SURGE (cm)	WATER(cm)	(TIME,s)	HEAVE (cm)	SURGE (cm)	WATER(cm)
1	1,25	-5,5	74	21	-1,25	8	69	41	0,75	6,5	75
2	1,25	-9	75	22	-0,75	-3	65	42	0,75	-3,5	67
3	1,25	2,5	77	23	1,25	-7	75	43	1,25	6,5	75
4	1,25	1	65	24	0,75	0	74	44	-0,25	-6	74
5	-0,25	2	75	25	1,25	3	76	45	-1,25	-6	72,5
6	0,75	-10,5	74	26	1,25	-9	74	46	-0,25	2	72
7	0,75	1	72,5	27	-0,25	-6	72	47	0,75	9	71
8	-0,25	-6	72	28	0,75	-0,5	72	48	0,75	0	66
9	-0,25	-0,5	67	29	0,75	-5,5	67	49	-0,25	7	78
10	-1,25	-5,5	74	30	1,25	6,5	74	50	0,75	-6	65
11	0,75	6,5	76	31	-0,25	-6	76	51	0,75	0	75
12	0,75	-6	74	32	-1,25	-6	65	52	1,25	7	74
13	0,75	9	75	33	-0,25	2	75	53	-0,25	0	72,5
14	-0,25	10,5	70	34	0,75	-10,5	74	54	0,75	7	72
15	0,75	0	65	35	0,75	1	72,5	55	0,75	13	72
16	0,75	7	75	36	-0,25	-6	72	56	1,25	3	66,5
17	-0,25	10,5	70	37	0,75	-0,5	67	57	-0,25	-0,5	73
18	-0,25	-1	62	38	0,75	-5,5	74	58	-1,25	-5,5	72
19	0,75	-7	65	39	1,25	6,5	76	59	-0,25	6,5	79
20	0,75	-9	75	40	-0,25	-6	74	60	0,75	10,5	65

CORRECTED VALUE

(TIME,s)	HEAVE (cm)	SURGE (cm)	WATER(cm)	(TIME,s)	HEAVE (cm)	SURGE (cm)	WATER(cm)	(TIME,s)	HEAVE (cm)	SURGE (cm)	WATER(cm)
1	2,1	-9,2	74	21	-2,1	13,4	69	41	1,3	10,9	75
2	2,1	-15,0	75	22	-1,3	-5,0	65	42	1,3	-5,8	67
3	2,1	4,2	77	23	2,1	-11,7	75	43	2,1	10,9	75
4	2,1	1,7	65	24	1,3	0,0	74	44	-0,4	-10,0	74
5	-0,4	3,3	75	25	2,1	5,0	76	45	-2,1	-10,0	72,5
6	1,3	-17,5	74	26	2,1	-15,0	74	46	-0,4	3,3	72
7	1,3	1,7	72,5	27	-0,4	-10,0	72	47	1,3	15,0	71
8	-0,4	-10,0	72	28	1,3	-0,8	72	48	1,3	0,0	66
9	-0,4	-0,8	67	29	1,3	-9,2	67	49	-0,4	11,7	78
10	-2,1	-9,2	74	30	2,1	10,9	74	50	1,3	-10,0	65
11	1,3	10,9	76	31	-0,4	-10,0	76	51	1,3	0,0	75
12	-0,4	-0,8	74	32	-2,1	-10,0	65	52	2,1	11,7	74
13	1,3	15,0	75	33	-0,4	3,3	75	53	-0,4	0,0	72,5
14	-0,4	17,5	70	34	1,3	-17,5	74	54	1,3	11,7	72
15	1,3	0,0	65	35	1,3	1,7	72,5	55	1,3	21,7	72
16	1,3	11,7	75	36	-0,4	-10,0	72	56	2,1	5,0	66,5
17	-0,4	17,5	70	37	1,3	-0,8	67	57	-0,4	-0,8	73
18	-0,4	-1,7	62	38	1,3	-9,2	74	58	-2,1	-9,2	72
19	1,3	-11,7	65	39	2,1	10,9	76	59	-0,4	10,9	79
20	1,3	-15,0	75	40	-0,4	-10,0	74	60	1,3	17,5	65

RESULT.

TEST NO: **5**

1 Actual Wave Height (cm) : 12,65

2 Actual Wave Period (s) : 5,07

3 Maximum Heave Responses (cm) : 17,5

4 Maximum Surge Responses (cm) : 34,9

5 Maximum Tilting Angle : 10

6 Current Velocity : 0,2

7 Responses

(TIME,s)	HEAVE (cm)	SURGE (cm)	WATER(cm)	(TIME,s)	HEAVE (cm)	SURGE (cm)	WATER(cm)	(TIME,s)	HEAVE (cm)	SURGE (cm)	WATER(cm)
1	-4,4	8,25	68,25	21	4,95	2,75	67,7	41	-1,65	-1,65	75,95
2	0	-0,55	64,95	22	2,75	-11	76,5	42	4,4	7,7	64,95
3	3,85	5,5	67,7	23	-4,4	0	71	43	2,75	2,75	67,7
4	4,95	-6,05	77,05	24	-5,5	8,25	67,7	44	0,55	-2,75	75,97
5	2,2	-12,1	70,45	25	-2,75	8,25	64,95	45	2,2	-11	75,95
6	-5,5	-11	66,05	26	0,55	-4,4	67,7	46	-5,5	8,25	65,5
7	-2,75	-1,65	64,95	27	4,95	-12,65	75,97	47	-2,75	8,25	67,7
8	0,55	7,7	67,7	28	2,75	-11	75,95	48	0,55	-4,4	75,97
9	4,95	2,75	76,5	29	-4,4	8,25	64,95	49	4,95	-12,65	75,95
10	2,75	-11	71	30	-5,5	-11	67,7	50	2,75	-11	64,95
11	-4,4	0	67,7	31	-2,75	-1,65	75,97	51	-4,4	1,65	67,7
12	-5,5	8,25	64,95	32	0,55	7,7	75,95	52	-5,5	-11	75,97
13	-1,65	8,25	67,7	33	2,2	2,75	65,5	53	-2,75	-1,65	75,95
14	4,4	-4,4	75,97	34	-5,5	-2,75	67,7	54	0,55	7,7	65,5
15	2,75	-12,65	75,95	35	-2,75	0	76,5	55	4,95	2,75	67,7
16	0,55	-11	64,95	36	0,55	8,25	71	56	2,75	-11	76,5
17	2,2	1,65	67,7	37	4,95	8,25	67,7	57	-4,4	0	71
18	-5,5	-11	75,97	38	2,75	-4,4	64,95	58	-5,5	8,25	67,7
19	-2,75	-1,65	75,95	39	-4,4	-12,65	67,7	59	-2,75	8,25	64,95
20	0,55	7,7	65,5	40	-5,5	-11	75,97	60	0,55	-4,4	67,7

CORRECTED VALUE

(TIME,s)	HEAVE (cm)	SURGE (cm)	WATER(cm)	(TIME,s)	HEAVE (cm)	SURGE (cm)	WATER(cm)	(TIME,s)	HEAVE (cm)	SURGE (cm)	WATER(cm)
1	-7,3	13,8	68,25	21	8,3	4,6	67,7	41	-2,8	-2,8	75,95
2	0,0	-0,9	64,95	22	4,6	-18,4	76,5	42	7,3	12,9	64,95
3	6,4	9,2	67,7	23	-7,3	0,0	71	43	4,6	4,6	67,7
4	8,3	-10,1	77,05	24	-9,2	13,8	67,7	44	0,9	-4,6	75,97
5	3,7	-20,2	70,45	25	-4,6	13,8	64,95	45	3,7	-18,4	75,95
6	-9,2	-18,4	66,05	26	0,9	-7,3	67,7	46	-9,2	13,8	65,5
7	-4,6	-2,8	64,95	27	8,3	-21,1	75,97	47	-4,6	13,8	67,7
8	0,9	12,9	67,7	28	4,6	-18,4	75,95	48	0,9	-7,3	75,97
9	8,3	4,6	76,5	29	-7,3	13,8	64,95	49	8,3	-21,1	75,95
10	4,6	-18,4	71	30	-9,2	-18,4	67,7	50	4,6	-18,4	64,95
11	-7,3	0,0	67,7	31	-4,6	-2,8	75,97	51	-7,3	2,8	67,7
12	-9,2	13,8	64,95	32	0,9	12,9	75,95	52	-9,2	-18,4	75,97
13	-2,8	13,8	67,7	33	3,7	4,6	65,5	53	-4,6	-2,8	75,95
14	7,3	-7,3	75,97	34	-9,2	-4,6	67,7	54	0,9	12,9	65,5
15	4,6	-21,1	75,95	35	-4,6	0,0	76,5	55	8,3	4,6	67,7
16	0,9	-18,4	64,95	36	0,9	13,8	71	56	4,6	-18,4	76,5
17	3,7	2,8	67,7	37	8,3	13,8	67,7	57	-7,3	0,0	71
18	-9,2	-18,4	75,97	38	4,6	-7,3	64,95	58	-9,2	13,8	67,7
19	-4,6	-2,8	75,95	39	-7,3	-21,1	67,7	59	-4,6	13,8	64,95
20	0,9	12,9	65,5	40	-9,2	-18,4	75,97	60	0,9	-7,3	67,7

RESULT.

TEST NO: **6**

1 Actual Wave Height (cm) : 9,9

2 Actual Wave Period (s) : 2,01

3 Maximum Heave Responses (cm) : 7,3

4 Maximum Surge Responses (cm) : 10,1

5 Maximum Tilting Angle : 5

6 Current Velocity : 0,2

7 Responses

(TIME,s)	HEAVE (cm)	SURGE (cm)	WATER(cm)	(TIME,s)	HEAVE (cm)	SURGE (cm)	WATER(cm)	(TIME,s)	HEAVE (cm)	SURGE (cm)	WATER(cm)
1	-1,1	-1,1	67,7	21	0	2,75	65,5	41	3,3	-2,2	73,75
2	0	3,3	65,5	22	-1,1	-2,2	73,75	42	-1,1	2,2	64,95
3	3,3	-2,2	73,75	23	-1,1	2,2	64,95	43	2,2	-1,65	75,4
4	-1,1	2,2	64,95	24	2,2	-1,65	75,4	44	-1,1	3,85	67,7
5	2,2	-1,65	75,4	25	-1,1	3,85	67,7	45	-1,1	-1,1	64,95
6	-1,1	3,85	67,7	26	-1,1	-1,1	64,95	46	1,65	2,75	73,75
7	-1,1	-1,1	67,7	27	1,65	2,75	73,75	47	2,75	-1,1	67,7
8	1,65	2,75	75,4	28	2,75	-1,1	67,7	48	-1,1	-2,2	73,75
9	2,75	-1,1	67,7	29	-1,1	-2,2	73,75	49	-1,1	2,2	64,95
10	-1,1	-2,2	73,75	30	-1,1	2,2	64,95	50	2,2	-1,65	75,4
11	-1,1	2,2	64,95	31	2,2	-1,65	75,4	51	-1,1	3,85	67,7
12	2,2	-1,65	75,4	32	-1,1	3,85	64,95	52	-1,1	-1,1	67,7
13	-1,1	3,85	67,7	33	-1,1	-1,1	67,7	53	1,65	2,75	71
14	-1,1	-1,1	64,95	34	1,65	2,75	75,4	54	2,75	-1,1	67,7
15	1,65	2,75	75,4	35	2,75	-1,1	67,7	55	3,3	-2,2	73,75
16	2,75	-1,1	67,7	36	-1,1	-2,2	73,75	56	-1,1	2,2	64,95
17	3,3	-2,2	73,75	37	-1,1	2,2	64,95	57	2,2	-1,65	75,4
18	-1,1	2,2	64,95	38	2,2	-1,65	75,4	58	-1,1	3,85	67,7
19	2,2	-1,65	75,4	39	-1,1	3,85	67,7	59	-1,1	-1,1	67,7
20	-1,1	3,85	67,7	40	0	3,3	65,5	60	1,65	2,75	71

CORRECTED VALUE

(TIME,s)	HEAVE (cm)	SURGE (cm)	WATER(cm)	(TIME,s)	HEAVE (cm)	SURGE (cm)	WATER(cm)	(TIME,s)	HEAVE (cm)	SURGE (cm)	WATER(cm)
1	-1,8	-1,8	67,7	21	0,0	4,6	65,5	41	5,5	-3,7	73,75
2	0,0	5,5	65,5	22	-1,8	-3,7	73,75	42	-1,8	3,7	64,95
3	5,5	-3,7	73,75	23	-1,8	3,7	64,95	43	3,7	-2,8	75,4
4	-1,8	3,7	64,95	24	3,7	-2,8	75,4	44	-1,8	6,4	67,7
5	3,7	-2,8	75,4	25	-1,8	6,4	67,7	45	-1,8	-1,8	64,95
6	-1,8	6,4	67,7	26	-1,8	-1,8	64,95	46	2,8	4,6	73,75
7	-1,8	-1,8	67,7	27	2,8	4,6	73,75	47	4,6	-1,8	67,7
8	2,8	4,6	75,4	28	4,6	-1,8	67,7	48	-1,8	-3,7	73,75
9	4,6	-1,8	67,7	29	-1,8	-3,7	73,75	49	-1,8	3,7	64,95
10	-1,8	-3,7	73,75	30	-1,8	3,7	64,95	50	3,7	-2,8	75,4
11	-1,8	3,7	64,95	31	3,7	-2,8	75,4	51	-1,8	6,4	67,7
12	3,7	-2,8	75,4	32	-1,8	6,4	64,95	52	-1,8	-1,8	67,7
13	-1,8	6,4	67,7	33	-1,8	-1,8	67,7	53	2,8	4,6	71
14	-1,8	-1,8	64,95	34	2,8	4,6	75,4	54	4,6	-1,8	67,7
15	2,8	4,6	75,4	35	4,6	-1,8	67,7	55	5,5	-3,7	73,75
16	4,6	-1,8	67,7	36	-1,8	-3,7	73,75	56	-1,8	3,7	64,95
17	5,5	-3,7	73,75	37	-1,8	3,7	64,95	57	3,7	-2,8	75,4
18	-1,8	3,7	64,95	38	3,7	-2,8	75,4	58	-1,8	6,4	67,7
19	3,7	-2,8	75,4	39	-1,8	6,4	67,7	59	-1,8	-1,8	67,7
20	-1,8	6,4	67,7	40	0,0	5,5	65,5	60	2,8	4,6	71

RESULT.

TEST NO: **7**

1 Actual Wave Height (cm) : 27,5

2 Actual Wave Period (s) : 5

3 Maximum Heave Responses (cm) : 25,7

4 Maximum Surge Responses (cm) : 51,4

5 Maximum Tilting Angle : 8

6 Current Velocity : 0,2

7 Responses

(TIME,s)	HEAVE (cm)	SURGE (cm)	WATER(cm)	(TIME,s)	HEAVE (cm)	SURGE (cm)	WATER(cm)	(TIME,s)	HEAVE (cm)	SURGE (cm)	WATER(cm)
1	-8,25	-16,5	64,95	21	-2,75	7,7	68,8	41	-2,75	7,7	68,8
2	-6,6	-13,2	68,25	22	2,75	-6,6	87,5	42	5,5	-6,6	87,5
3	-5,5	0	61,65	23	-5,5	-6,6	64,95	43	-5,5	-6,6	64,95
4	-2,75	7,7	68,8	24	-8,25	-5,5	62,2	44	-8,25	-15,4	64,4
5	5,5	-15,4	87,5	25	-8,25	8,8	62,2	45	-8,25	8,8	62,2
6	-5,5	-6,6	64,95	26	-5,5	11	68,25	46	-5,5	11	68,25
7	-8,25	-5,5	64,4	27	2,75	-13,75	93	47	2,75	-13,75	93
8	-8,25	8,8	62,2	28	-8,8	-15,4	63,85	48	-8,8	-15,4	63,85
9	-5,5	11	68,25	29	-9,9	-6,6	63,85	49	-9,9	-6,6	63,85
10	2,75	-13,75	93	30	-9,35	8,25	62,2	50	-9,35	8,25	62,75
11	-8,8	-15,4	63,85	31	-5	15,4	68,25	51	-9,35	11	62,2
12	-9,9	-6,6	63,85	32	2,75	-13,75	87,5	52	2,75	-13,75	68,25
13	-9,35	8,25	62,75	33	5,5	-6,6	63,85	53	5	-6,6	93
14	-5,5	15,4	66,66	34	-5,5	-6,6	64,95	54	-5,5	-6,6	63,85
15	2,75	-13,75	93	35	-8,25	-5,5	64,4	55	-8,25	-5,5	64,4
16	5,5	-6,6	87,5	36	-8,25	8,8	62,2	56	-8,25	8,8	62,2
17	-5,5	-6,6	64,95	37	-5,5	11	68,25	57	-5,5	11	93
18	-8,25	-5,5	64,4	38	-8,25	-15,4	64,4	58	-8,25	-6,6	64,4
19	-8,25	8,8	62,2	39	-8,25	8,8	62,2	59	-8,25	8,8	62,2
20	-5,5	11	68,25	40	-5,5	11	62,2	60	-5,5	11	68,25

CORRECTED VALUE

(TIME,s)	HEAVE (cm)	SURGE (cm)	WATER(cm)	(TIME,s)	HEAVE (cm)	SURGE (cm)	WATER(cm)	(TIME,s)	HEAVE (cm)	SURGE (cm)	WATER(cm)
1	-13,8	-27,6	64,95	21	-4,6	12,9	68,8	41	-4,6	12,9	68,8
2	-11,0	-22,0	68,25	22	4,6	-11,0	87,5	42	9,2	-11,0	87,5
3	-9,2	0,0	61,65	23	-9,2	-11,0	64,95	43	-9,2	-11,0	64,95
4	-4,6	12,9	68,8	24	-13,8	-9,2	62,2	44	-13,8	-25,7	64,4
5	9,2	-25,7	87,5	25	-13,8	14,7	62,2	45	-13,8	14,7	62,2
6	-9,2	-11,0	64,95	26	-9,2	18,4	68,25	46	-9,2	18,4	68,25
7	-13,8	-9,2	64,4	27	4,6	-23,0	93	47	4,6	-23,0	93
8	-13,8	14,7	62,2	28	-14,7	-25,7	63,85	48	-14,7	-25,7	63,85
9	-9,2	18,4	68,25	29	-16,5	-11,0	63,85	49	-16,5	-11,0	63,85
10	4,6	-23,0	93	30	-15,6	13,8	62,2	50	-15,6	13,8	62,75
11	-14,7	-25,7	63,85	31	-8,4	25,7	68,25	51	-15,6	18,4	62,2
12	-16,5	-11,0	63,85	32	4,6	-23,0	87,5	52	4,6	-23,0	68,25
13	-15,6	13,8	62,75	33	9,2	-11,0	63,85	53	8,4	-11,0	93
14	-9,2	25,7	66,66	34	-9,2	-11,0	64,95	54	-9,2	-11,0	63,85
15	4,6	-23,0	93	35	-13,8	-9,2	64,4	55	-13,8	-9,2	64,4
16	9,2	-11,0	87,5	36	-13,8	14,7	62,2	56	-13,8	14,7	62,2
17	-9,2	-11,0	64,95	37	-9,2	18,4	68,25	57	-9,2	18,4	93
18	-13,8	-9,2	64,4	38	-13,8	-25,7	64,4	58	-13,8	-11,0	64,4
19	-13,8	14,7	62,2	39	-13,8	14,7	62,2	59	-13,8	14,7	62,2
20	-9,2	18,4	68,25	40	-9,2	18,4	62,2	60	-9,2	18,4	68,25

RESULT.

TEST NO: **8**

1 Actual Wave Height (cm) : 20

2 Actual Wave Period (s) : 2

3 Maximum Heave Responses (cm) : 13,4

4 Maximum Surge Responses (cm) : 27,6

5 Maximum Tilting Angle : 4

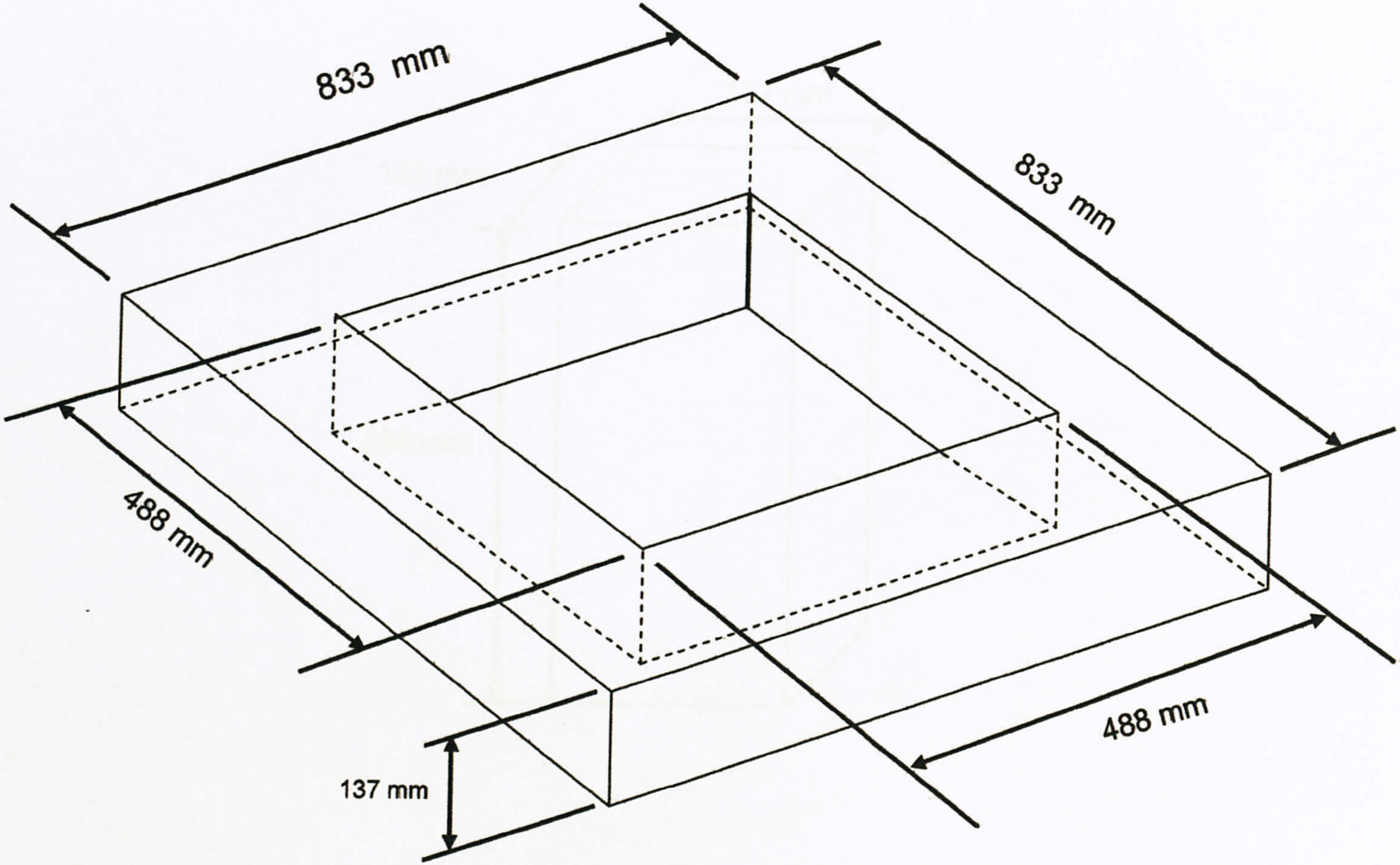
6 Responses

(TIME,s)	HEAVE (cm)	SURGE (cm)	WATER(cm)	(TIME,s)	HEAVE (cm)	SURGE (cm)	WATER(cm)	(TIME,s)	HEAVE (cm)	SURGE (cm)	WATER(cm)
1	-2	5,25	74	21	-2	-7,25	69	41	-2	6,25	75
2	0	-0,75	75	22	0	5,75	65	42	0	-5,25	67
3	2	3,25	77	23	2	-8,25	75	43	2	7,25	75
4	0	-6,75	65	24	-2	-4,75	74	44	0	-4,75	74
5	2	6,25	75	25	0	5,25	76	45	2	8,25	72,5
6	-1,5	-5,25	74	26	2	-7,75	74	46	-1,5	-4,75	72
7	-0,5	7,25	72,5	27	0	7,25	72	47	-0,5	6,75	71
8	-2	-4,75	72	28	2	-7,25	72	48	-2	-5,75	66
9	-1	8,25	67	29	0,5	5,75	67	49	0	7,25	78
10	1	-4,75	74	30	-1	-8,25	74	50	2	-4,75	65
11	0	6,25	76	31	-2	4,75	76	51	0	8,25	75
12	0	-4,75	74	32	0	-6,75	65	52	2	-4,75	74
13	-1	6,25	75	33	2	5,25	75	53	-1,5	5,25	72,5
14	-2	-5,25	70	34	0	-7,75	74	54	-0,5	-6,25	72
15	0	7,25	65	35	2	7,25	72,5	55	-2	7,25	72
16	2	-4,75	75	36	-1,5	-8,25	72	56	-1,5	-5,75	66,5
17	0	4,25	70	37	-0,5	4,75	67	57	-1	6,75	73
18	2	-4,75	65	38	-1,5	-7,25	74	58	0	-8,75	72
19	0	6,25	65	39	0,5	5,75	76	59	1,5	6,25	79
20	0	-4,75	75	40	-1	-8,25	74	60	0,5	-4,75	65

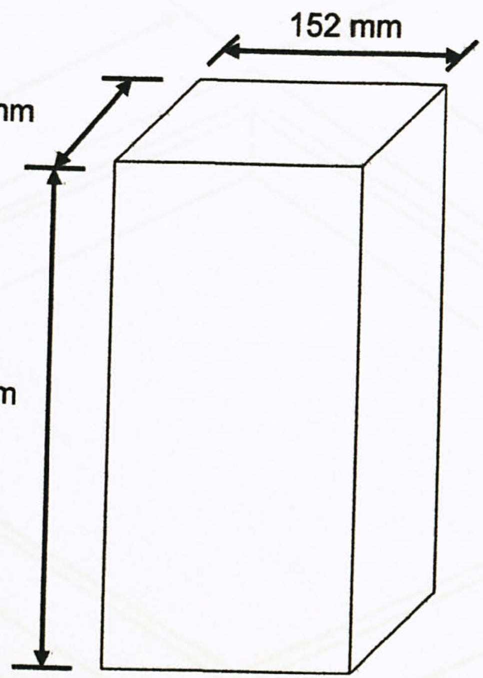
CORRECTED VALUE

(TIME,s)	HEAVE (cm)	SURGE (cm)	WATER(cm)	(TIME,s)	HEAVE (cm)	SURGE (cm)	WATER(cm)	(TIME,s)	HEAVE (cm)	SURGE (cm)	WATER(cm)
1	-3,3	8,8	74	21	-3,3	-12,1	69	41	-3,3	10,4	75
2	0,0	-1,3	75	22	0,0	9,6	65	42	0,0	-8,8	67
3	3,3	5,4	77	23	3,3	-13,8	75	43	3,3	12,1	75
4	0,0	-11,3	65	24	-3,3	-7,9	74	44	0,0	-7,9	74
5	3,3	10,4	75	25	0,0	8,8	76	45	3,3	13,8	72,5
6	-2,5	-8,8	74	26	3,3	-12,9	74	46	-2,5	-7,9	72
7	-0,8	12,1	72,5	27	0,0	12,1	72	47	-0,8	11,3	71
8	-3,3	-7,9	72	28	3,3	-12,1	72	48	-3,3	-9,6	66
9	-1,7	13,8	67	29	0,8	9,6	67	49	0,0	12,1	78
10	1,7	-7,9	74	30	-1,7	-13,8	74	50	3,3	-7,9	65
11	0,0	10,4	76	31	-3,3	7,9	76	51	0,0	13,8	75
12	-1,7	-7,9	74	32	0,0	-11,3	65	52	3,3	-7,9	74
13	-1,7	10,4	75	33	3,3	8,8	75	53	-2,5	8,8	72,5
14	-3,3	-8,8	70	34	0,0	-12,9	74	54	-0,8	-10,4	72
15	0,0	12,1	65	35	3,3	12,1	72,5	55	-3,3	12,1	72
16	3,3	-7,9	75	36	-2,5	-13,8	72	56	-2,5	-9,6	66,5
17	0,0	7,1	70	37	-0,8	7,9	67	57	-1,7	11,3	73
18	3,3	-7,9	65	38	-2,5	-12,1	74	58	0,0	-14,6	72
19	0,0	10,4	65	39	0,8	9,6	76	59	2,5	10,4	79
20	0,0	-7,9	75	40	-1,7	-13,8	74	60	0,8	-7,9	65

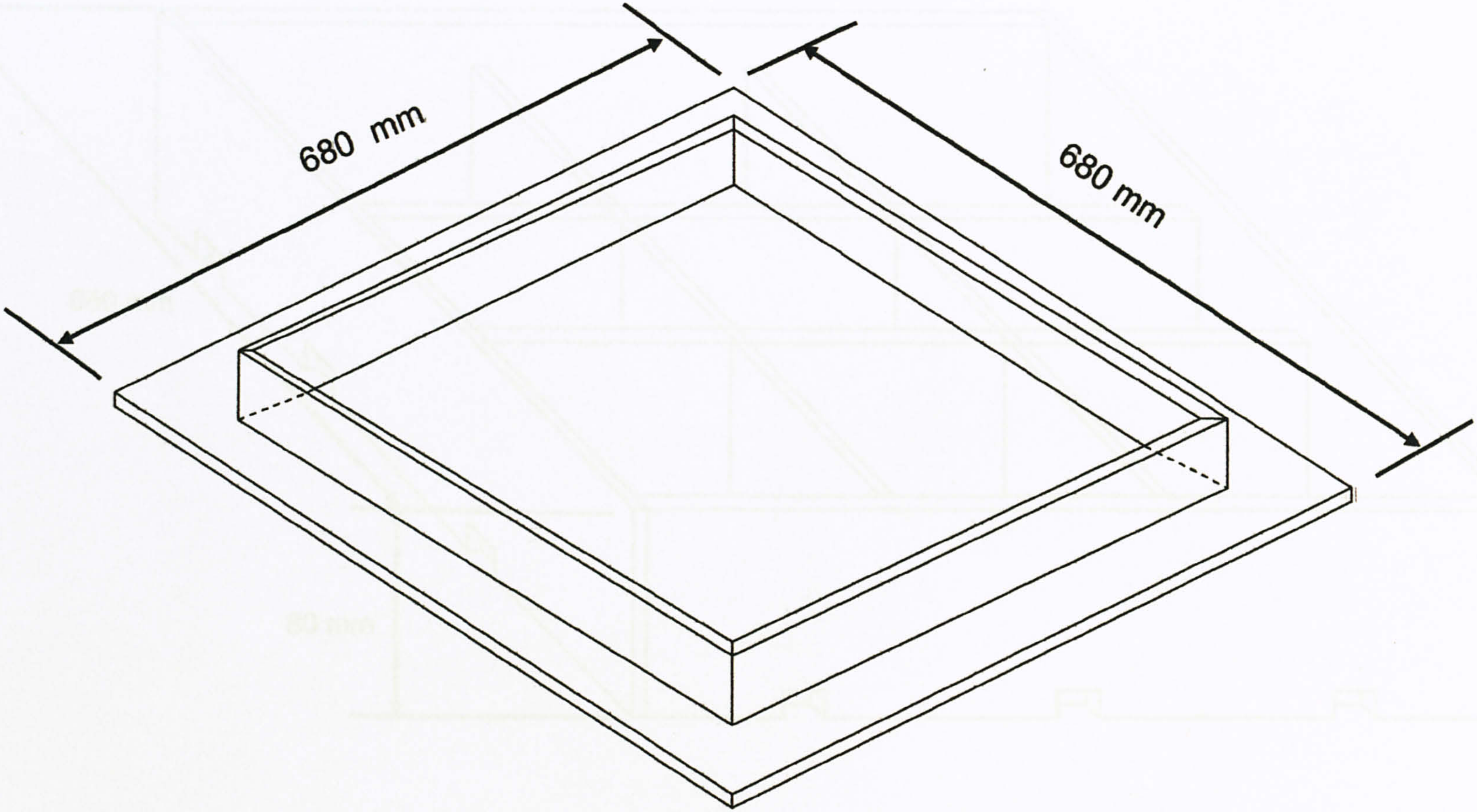
C DIMENSION OF STRUCTURAL COMPONENTS



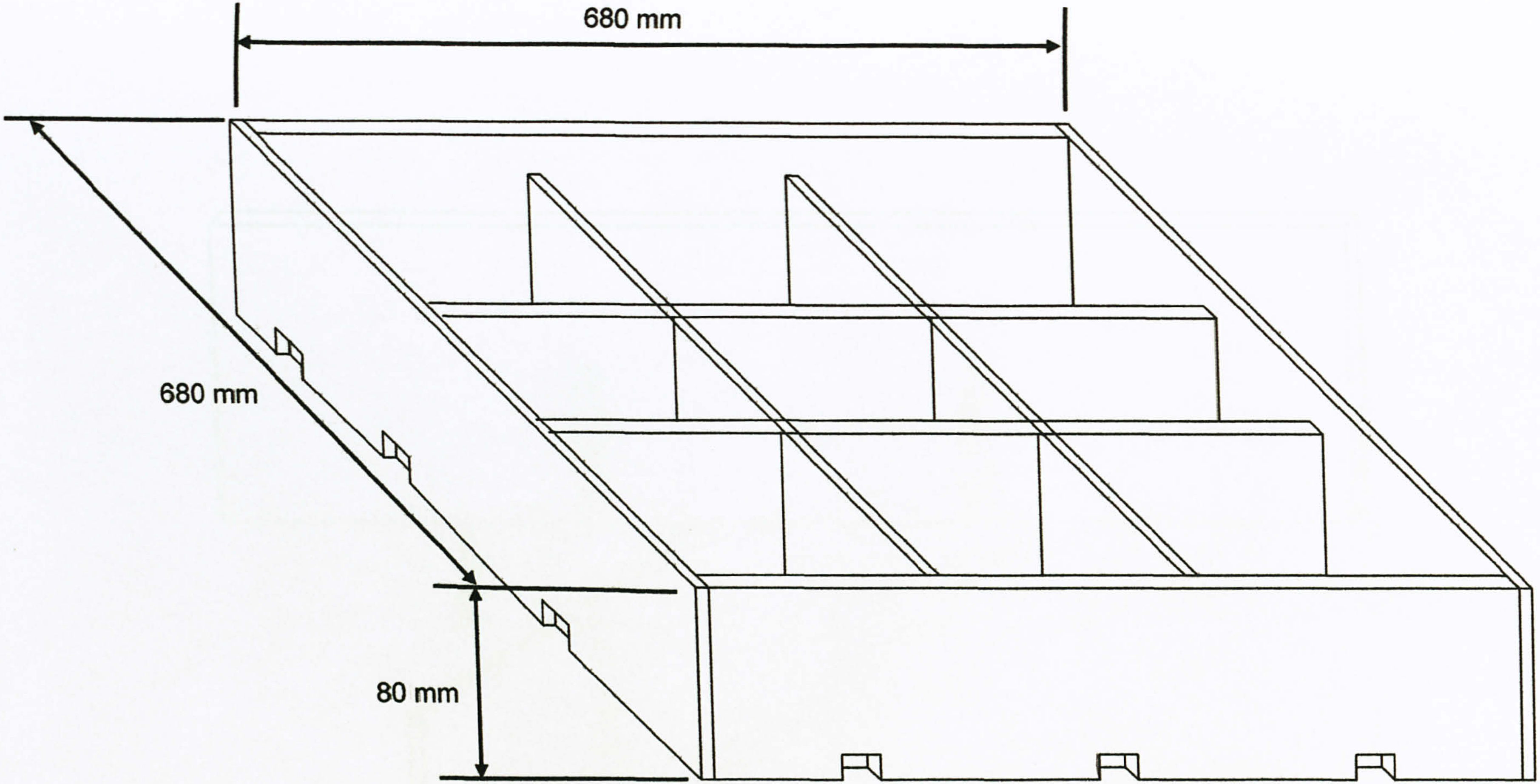
Pontoon



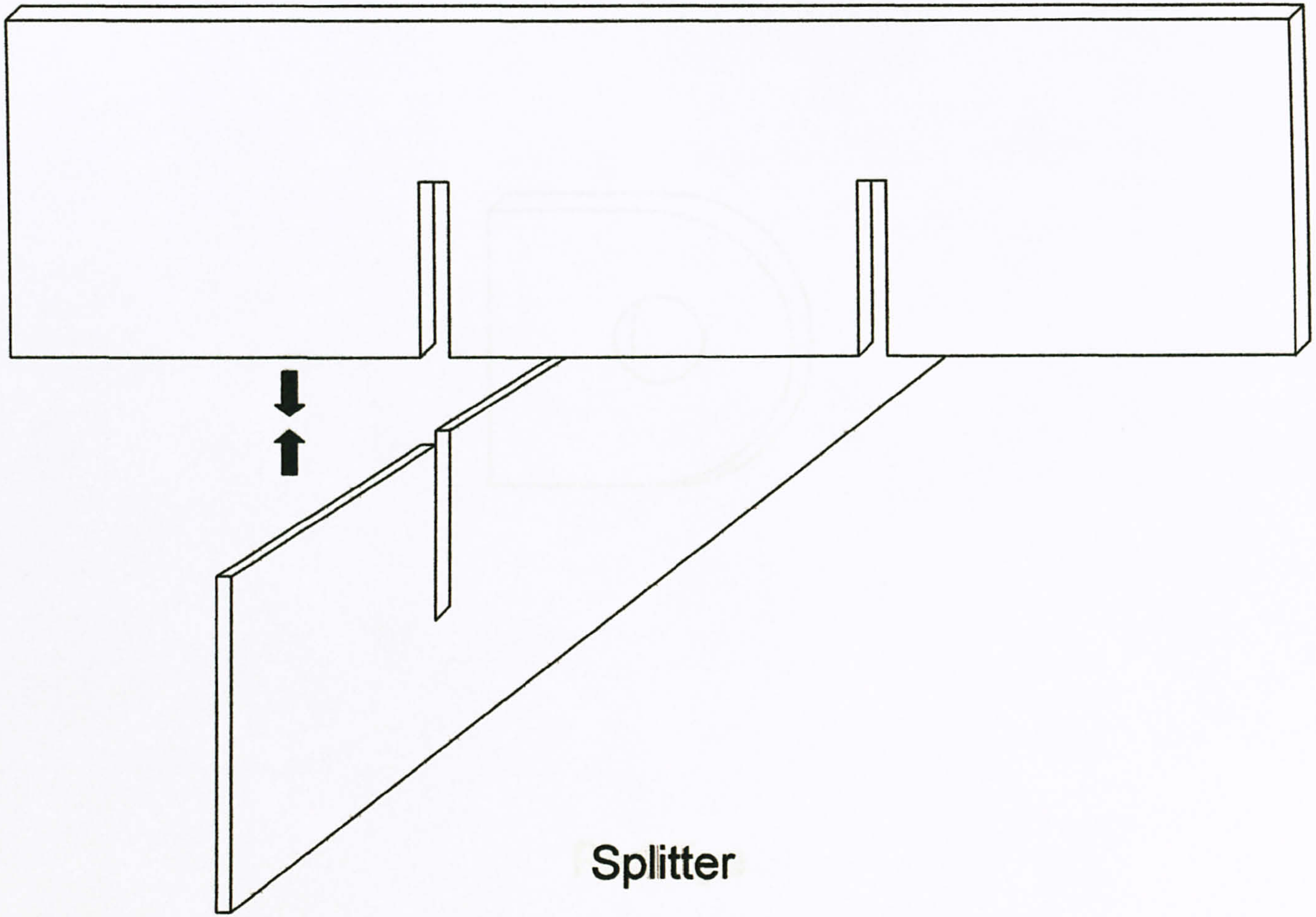
Column



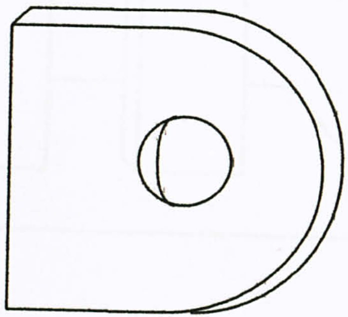
Topside Cover



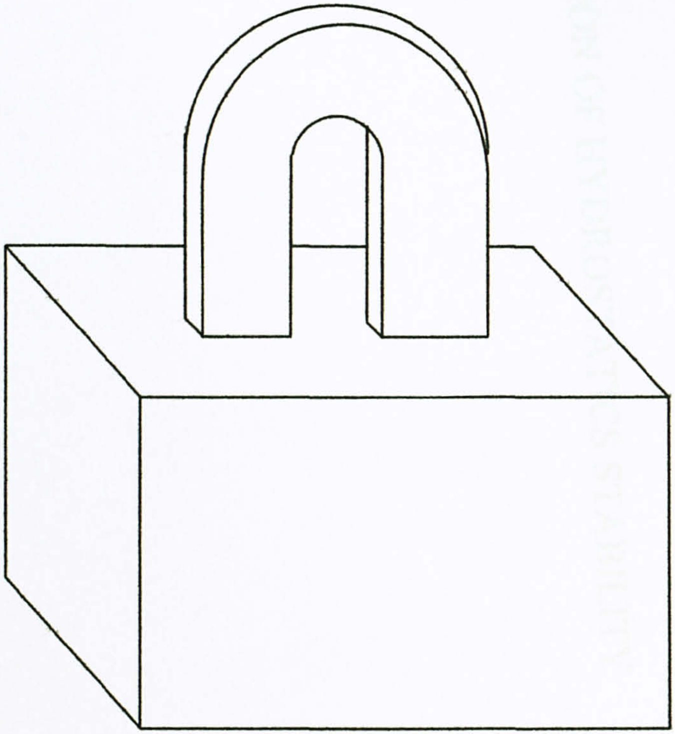
Topsides



Splitter



Pad Eye

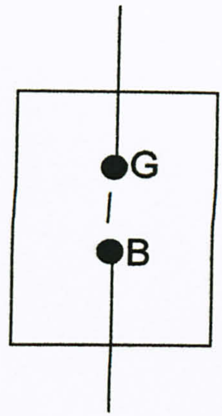


Anchor

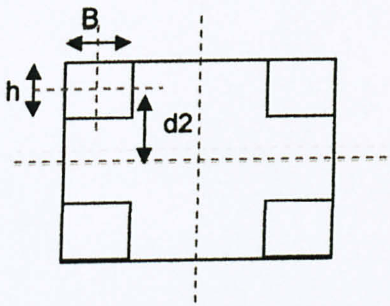
D CALCULATION OF HYDROSTATICS STABILITY

Hydrostatic Stability

$$\overline{GM} = \frac{I\,x'x'}{V} - \overline{BG}$$



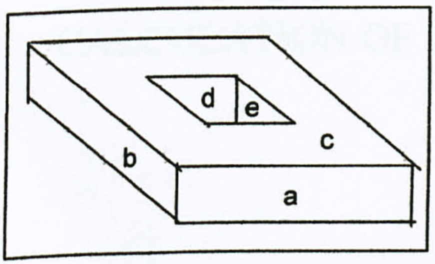
Ixx	=	Bh3/12
	=	0,15 x 0,15^3 / 12
	=	4,22E-05 m4
Ix'x'	=	4 (Ixx + Ac + d2)
	=	4 (4,22E-05 + (0,15 x 0,15))
	=	0,090 m4
V	=	(Vp) + 4 (Ac x df)
	=	((0,83 x 0,83 x 0,137) - (0,52 x 0,52 x 0,137)) + 4 (0,15 x 0,15 x 0,123)
	=	0,0684 m3
B	=	0,211 m
G	=	0,222 m
BG	=	0,011
GM	=	**<u>1,307</u> m** **>0 Stable**

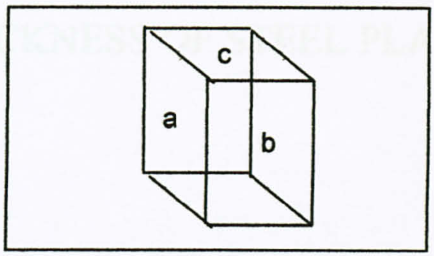


E CALCULATION OF BASE WEIGHT

Weight Calculation of Tested Model

Component	Nos	Thickness(mm)	Width(m)	Length(m)	Weight(kg)
Pontoon					
a	2	4	0,137	0,83	1,08
b	2	4	0,137	0,822	1,07
d	2	4	0,137	0,5	0,65
e	2	4	0,137	0,492	0,64
c	2	4	0,31	1,35	3,98
Wt.pontoon					**7,43**
Column					
a	2	4	0,15	0,234	0,33
b	2	4	0,142	0,234	0,32
c	2	4	0,15	0,15	0,21
Wt. Column					0,86
4 nos	4				**3,46**
Pontoon + Column					**10,89**
Wt. Topsides					**5,27**





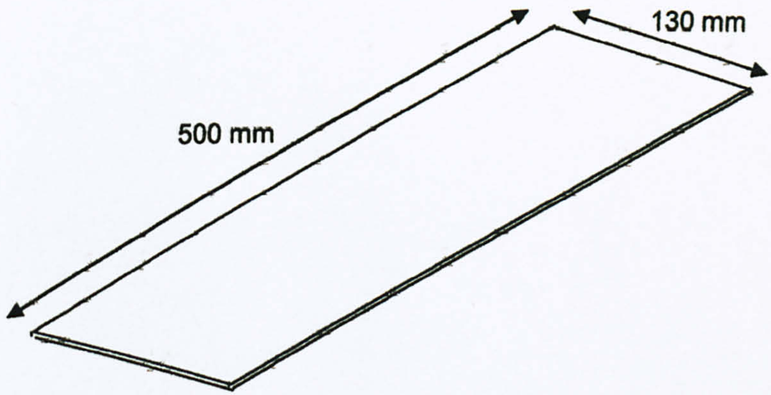
F CALCULATION OF THICKNESS OF STEEL PLATES

Steel Plate (added weight)
Determination the thickness of the plate.

Total weight required	=	25 kg
Number of Plates	=	each side of surface of the pontoon
	=	16 NOS
Steel Density (Mild Steel)	=	7,850 kg/m3
Dimension of Steel		
Length (m)	=	0.50
Width (m)	=	0.13

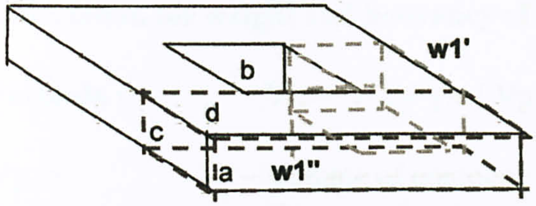
Formula :

25 kg	=	7,850 x t x 16 (length x width)
t	=	<u>**0.003 m**</u>
Each plate	=	7850 x t x 1 (length x width)
	=	**1,43 kg**
16 Nos	=	**22,86 kg**



G CALCULATION OF WEIGHT ALLOCATION

w1



W1 = **7,43 kg**
Steel plate = **1,43 kg**

	Component	Nos	Thickness(mm)	Width(m)	Length(m)	Weight(kg)
w1"	a	1	4	0,137	0,83	0,54
	b	1	4	0,137	0,52	0,34
	c	2	4	0,137	0,16	0,21
	d	2	4	0,83	0,15	1,19
1 x w1"	total					**2,27**

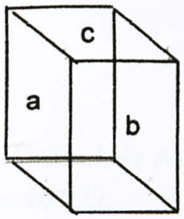
2 x w1' = W1 - 2*w1"
= 2,88 kg
1 x w1' = 1,44 kg

The steel plate is attached to each surface;

w1" = (1 x w1") + 4(1,43)
= 7,99 kg √

w1' = (1 x w1') + 4(1,43)
= 7,16 √

Total pontoon wt = **30,31** kg



Column Wt each = 0,86 kg
Sand weight = 3 kg
Total wt. 1 column = 3,86 kg √
4 nos = **15,44** kg

Topsides weight = 5,27 kg
Added Weight (9nos) = 2 kg
= 18
Total topsides wt. = **23,27** kg √

Total weight of tested model = **69,02 kg**

Calculation for weight and bouyancy of structure

Formula : **$W1 + W2 = \gamma w$ [Vp + 4 Ac x (df - h1)]** **(i)**

Vp = Volume of pontoon
Ac = Cross-sectional area of column
γw = Density of water = 9806 N/m3
df = Required draft = 25 cm
h1 = Height of pontoon = 13.7 cm

Pontoon	Outer (cm)	Inner (cm)
Length,L	83	52
Width,W	83	52
Thickness,T	13,7	13,7
Volume,V	**94379,3**	**37044,8**

column	(cm)
Length,L	15
Width,W	15
Thickness	24,3
Area	**225**

1. Calculate Vp

Vp (cm3) = Vo - Vi
= (Lo x Wo X Ho) - (Li x Wi x Hi)
= 94379,3 - 37044,8
= <u>57334,5</u>

2. Calculate Ac

Ac (cm2) = Length X Width
= <u>225</u>

3. Substitude in the equation (i).

Formula : W1 + W2 = γw [Vp + 4 Ac x (df - h1)]
Σ(W1 + W2 = 67 x 10 3 MT
= <u>67 kg</u>

4. Weight Allocation;

Topside	20 kg
Substructure	45 kg
Mooring + riser	2 kg
Total	67 kg

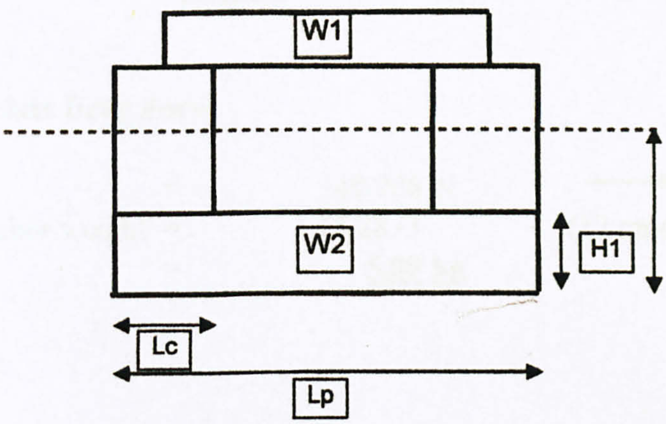
5. Added Weight = Required Weight - Current Weight

Topside	
Required weight(kg)	20
Current weight (kg)	5,27
Added weight (kg)	14,73

Substructure (Pontoon + Column)	
Required weight(kg)	45
Current weight (kg)	10,42
Added weight (kg)	34,58

Added weight (kg)	
Pontoon	25
Column	9,5

Material Selection
Steel Plates
Sand



Drag Force Calculation

Formula :

F = 1/2 x Cd x ρw x A x v2

A	=	Area of Submerged Surface
Cd	=	Drag Coefficient, 0.65 (Clean Members)
ρw	=	Density of Water, 9806 N/m3
v2	=	Velocity of Current, 0.60 m/s

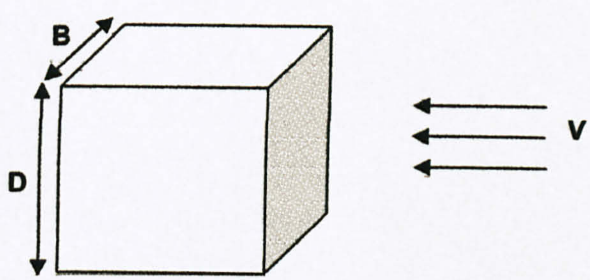
1. Calculate the Area of Submerged Surface.

Area (m2)

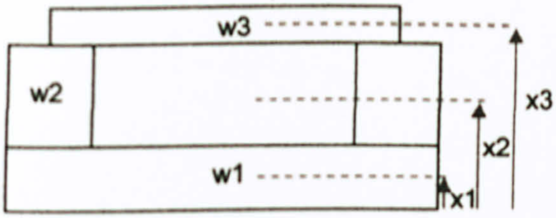
Pontoon	=	0,83 x 0,137
	=	0,11371
Column	=	0,15 x 0,113
	=	0,01695
Total	=	**0,13066**

2. Calculate Drag Force

F d	=	149,906 N	→ 15,28 kg
Each anchor weight	=	15,28 /3	(12 mooring lines with 3 on each side)
	=	**5,00 kg**	



H CALCULATION OF CENTER OF GRAVITY

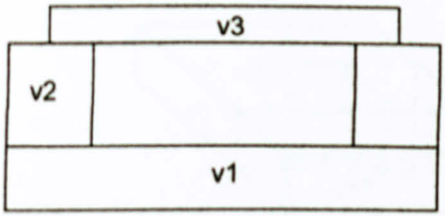


Xcog = $\frac{w1x1 + w2x2 + w4x4 ..}{w1 + w2 + w3 + ...}$

component	element	x	w	wx
w1	a	0,0685	7,99	0,547608
	b	0,0685	7,99	0,547608
	c	0,0685	7,16	0,490509
	d	0,0685	7,16	0,490509
w2	a	0,254	3,86	0,98044
	b	0,254	3,86	0,98044
	c	0,254	3,86	0,98044
	d	0,254	3,86	0,98044
w3	a	0,4	23,27	9,308
Σ			69,02	15,306

Xcog = **<u>0,222</u> m**

I CALCULATION OF CENTER OF BUOYANCY

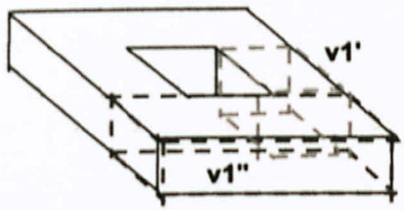


$$X_{cob} = \frac{v1x1 + v2x2 + v4x4 \ldots}{v1 + v2 + v3 + \ldots}$$

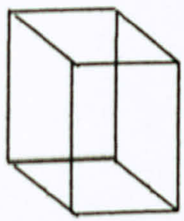
component	element	x	v	vx
w1	a	0,0685	0,017	0,001168
	b	0,0685	0,017	0,001168
	c	0,0685	0,011	0,000732
	d	0,0685	0,011	0,000732
w2	a	0,254	0,005	0,001337
	b	0,254	0,005	0,001337
	c	0,254	0,005	0,001337
	d	0,254	0,005	0,001337
w3	a	0,4	0,037	0,014797
Σ			0,11	0,023947

Xco~~g~~ b = 0,211 m

w1



	width	length	thickness	volume(m3)	
v1"	0,15	0,83	0,137	0,017	√
v1'	0,15	0,52	0,137	0,011	√
				0,028	



	width	length	thickness	volume(m3)	
v2	0,15	0,15	0,234	0,005	√
topsides	0,68	0,68	0,08	0,037	√

J CALIBRATION CURVE

Forward

Actual force (N)	Reading (kg)	Reading (N)	Displacement (cm)	Reverse Force (N)
4	0	0	0,2	-0,02
8	0,13	1,27491	0,6	-0,08
12	0,31	3,04017	0,9	-0,1
16	0,53	5,19771	1,3	-0,11
20	0,6	5,8842	1,5	-0,12